Ontario

Ontario Geological Survey
Open File Report 6120

Summary of Field Work and Other Activities 2003

2003

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ONTARIO GEOLOGICAL SURVEY

Open File Report 6120

Summary of Field Work and Other Activities 2003

Edited by

C.L. Baker, R.I. Kelly, J.R. Parker, J.A. Ayer and R.M. Easton

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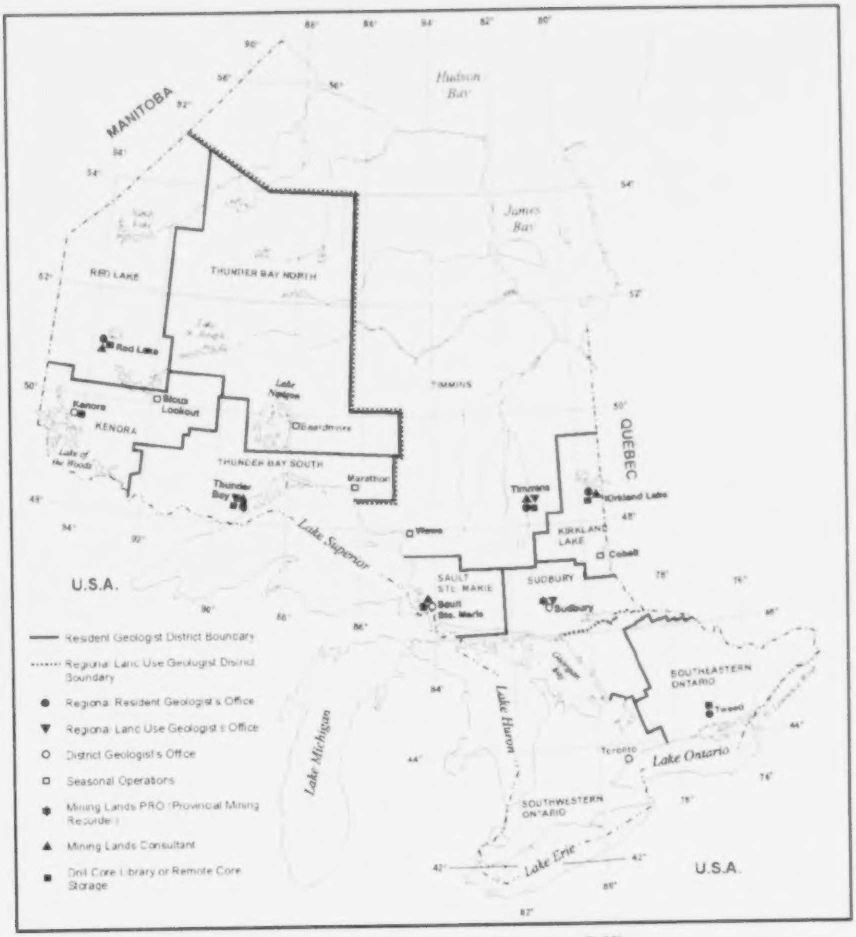
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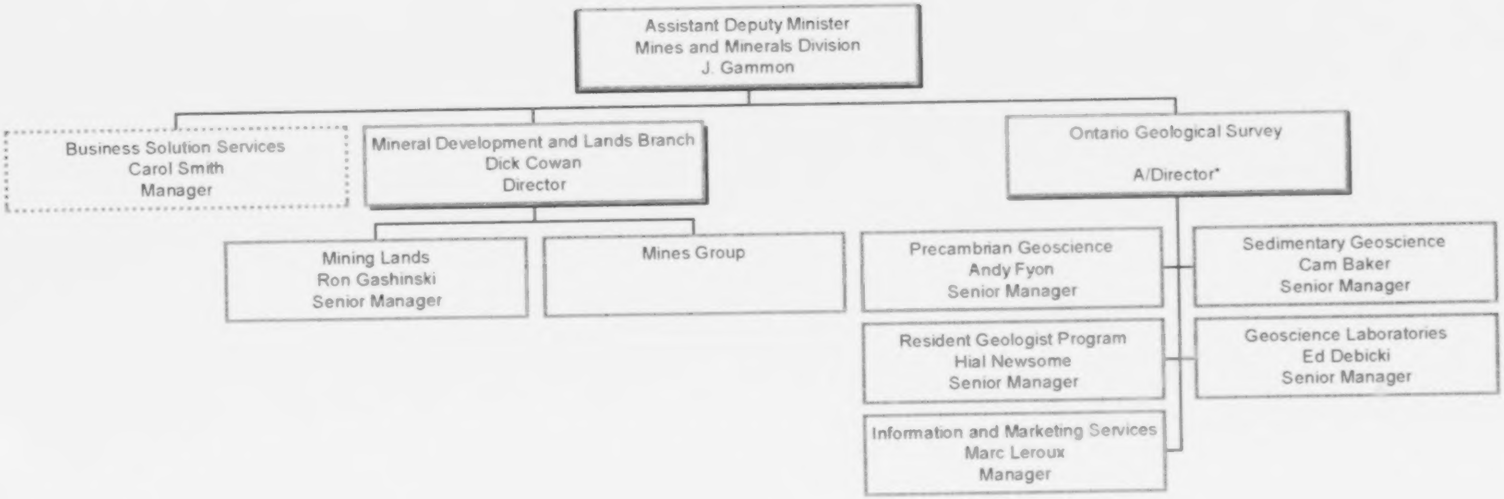
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[1]Executive Assistant to the Assistant Deputy Minister, Mines and Minerals Division
[2]Assistant Deputy Minister, Mines and Minerals Division, Ministry of Northern Development and Mines (MNDM)

INTRODUCTION

The Far North of Ontario, for the purposes of this report, principally comprises those lands north of the "Area of Undertaking", a term used by the Ministry of Natural Resources to identify the furthest extent of Forest Management planning and current commercial timber operations. The boundary also more or less reflects the area not accessible by all weather roads. To the west, it is bordered by Manitoba and, to the east, by Hudson Bay and James Bay, and comprises approximately 40% of Ontario's landmass.

First Nations people have existed in this area since before recorded history and are presently located within 33 relatively isolated and remote communities and reserves, with a population of close to 25 000. Unemployment is high, particularly among the youth, which often comprise over 60% of the community populations. The traditional way of life is still practised and valued, but is under greater and greater stress as time goes by. The increasing needs of the local population to support themselves and grow, combined with increasing attention of outside resource development interests, including hydro generation, mining and exploration, timber harvesting and tourism is resulting in greater interaction and potential for conflict. This, in part, arises as a result of disagreements between First Nations and Ontario on interpretations with respect to the existence and extent of rights, as well as differing interpretations of the meaning of words within treaties. Both First Nations and the private sector also poorly understand any legal obligations the private sector may have in terms of consultation with First Nations.

In 1999, Ontario Geological Survey projects were planned to address the poorly understood geology of some areas in the Far North in order to provide the basic information which could be utilized for both exploration and land use planning purposes. Recognizing the possible impacts on First Nation's communities, staff initiated a number of communications and relationship-building activities to increase awareness by First Nations of Ontario Geological Survey activities. On May 7, 2001, the Honourable D. Newman, the Ontario Minister of Northern Development and Mines (MNDM) at the time, declared "By moving to open up the Far North to mining and resource activities the government will create more opportunities for residents and help aboriginal communities become self-reliant." Following the success of the OGS activities, the Ministry of Northern Development and Mines in 2002 determined to continue and strengthen their relationship building by presenting some innovative approaches, which might benefit First Nations in these remote communities, without requiring them to jeopardize their positions with respect to the larger political issues they are pursuing.

Summary of Field Work and Other Activities 2003,
Ontario Geological Survey, Open File Report 6120, p.1-1 to 1-4.

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THE "3 OFFERS"

During a tour of Far North communities in 2002 by one of the authors, Assistant Deputy Minister J.B. Gammon, the majority of communities visited indicated support for mineral exploration and development. However, this support was conditional on explorationists respecting aboriginal and treaty rights in traditional use areas, consulting with First Nations at all stages of the mining process, minimizing impacts on traditional activities, compensating communities and/or individuals for activities that infringe on Aboriginal and treaty rights and sharing benefits with First Nation people and communities. Although the Crown does not necessarily support or agree with all of these wishes, the suggestions do provide the basis for developing initiatives that may address some of these concerns.

In order to advance positive relations with First Nations communities and to facilitate improved communications between these communities and exploration and mining companies, the Ministry of Northern Development and Mines initiated several activities to begin this process. The "3 Offers" represent one of these initiatives and are predicated on the premise that acceptance by First Nations would be voluntary and without prejudice to aboriginal and treaty rights. The offers include

- Withdrawing Land: Aboriginal Culturally Significant Sites in the Far North;
- License of Occupation: Community Mineral Resource Zone; and
- Facilitation: Traditional Use Areas.

Each of these can be implemented by the authority of the Minister of Northern Development and Mines without requiring new legislation. The MNDM Minister formally presented the offers in a written letter to the 31 Chiefs of the Far North First Nations on October 23, 2002, as a pilot project.

These offers are a vehicle to build capacity and understanding among First Nations in the north. Benefits to exploration and mining companies will accrue over the longer term as these communities become more aware and cognizant of the benefits which they can obtain through increased exploration activities in their areas.

Withdrawing Land: Aboriginal Culturally Significant Sites in the Far North

Family burial sites, traditional family camp sites, sites of spiritual significance, and historical structures are only a few examples of culturally significant sites. There is recognition that these areas should be protected from encroachment by outside development activities. Generally, the sites proposed should be less than 200 by 200 m in area and would be withdrawn from prospecting, staking, sale or lease, upon request by a First Nation situated in the Far North. A formal Band Council Resolution is required to accompany the request and must provide specific location co-ordinates and explanations as to why the sites are culturally significant. MNDM Mining Lands staff will review the requests against a set of defined criteria prior to making a recommendation for approval to the Minister. Under Subsections 35(1) through 35(4) of the *Mining Act*, the Minister may, by an order signed by him, withdraw the lands.

License of Occupation: Community Mineral Resource Zone

Areas adjacent to Reserves are sensitive to encroachment by outside activities because of the proximity of communities and homes to the boundaries in many instances. First Nations have suggested that they could also use lands surrounding the Reserves as a training ground to develop expertise in such early exploration activities as prospecting, staking, line-cutting, ground geophysics and soil geochemistry surveying techniques. MNDM's additional commitment of encouraging economic development in the north dovetails nicely with this idea. Not only could these zones provide the appropriate location for hands-on training, but could also lead to developing service-oriented businesses to support the exploration companies which have interests in the north. Additionally, if favourable geology is present within these zones, First Nations have the opportunity to enter into exploration partnerships with any other party, on their own terms, to explore the area. This type of joint venture agreement could provide experience in more advanced exploration projects and, ultimately, lead to possible revenue for the First Nations.

Under special circumstances, the Minister of the Ontario MNDM, with the approval of the Lieutenant Governor of Ontario, can issue a license of occupation to explore for minerals under the provision of Subsection 176(3) of the *Mining Act*. Using this provision, the ministry has developed a policy supporting the concept of Community Mineral Resource Zones, which will allow for the withdrawal of an area 1.6 km (4 claim units) in width around the entire boundary of a Reserve for a period of 10 years. This license can be renewed at the discretion of the Minister.

Similar to the previous offer, a formal Band Council Resolution is required to accompany the request. MNDM Mining Lands staff will review the requests submitted by either Chief or Band Manager against a set of defined criteria prior to making a recommendation for approval to the Minister.

Facilitation: Traditional Use Areas

Prospectors and explorationists often traverse Crown Land with no knowledge that they may be inadvertently affecting Aboriginal rights through their activities. Complicating the issue is the often-overlapping nature of traditional use areas by more than one First Nation. Although there is presently no legal requirement for these individuals to contact and inform First Nations of their presence, it is becoming a well-known best practise to do so in order to facilitate subsequent activities should an economic deposit be discovered. First Nations are also concerned for the health and safety of those working in the bush during periods of traditional hunts. Unfortunately, there are no published maps identifying these traditional use areas or the First Nations that have interests in the areas. In many cases, First Nation's people simply want to know who and what the individuals are doing and whether or not their activities will impact on their hunting, trapping or fishing activities. In many instances, if exploration companies or prospectors knew in advance which particular individuals and/or communities were being impacted, misunderstandings and conflicts could be avoided.

The Ministry has proposed that First Nations in the Far North identify traditional use boundaries. If provided, MNDM would ensure distribution of the information by the appropriate means to claim holders, according to conditions previously agreed-to with respective First Nations.

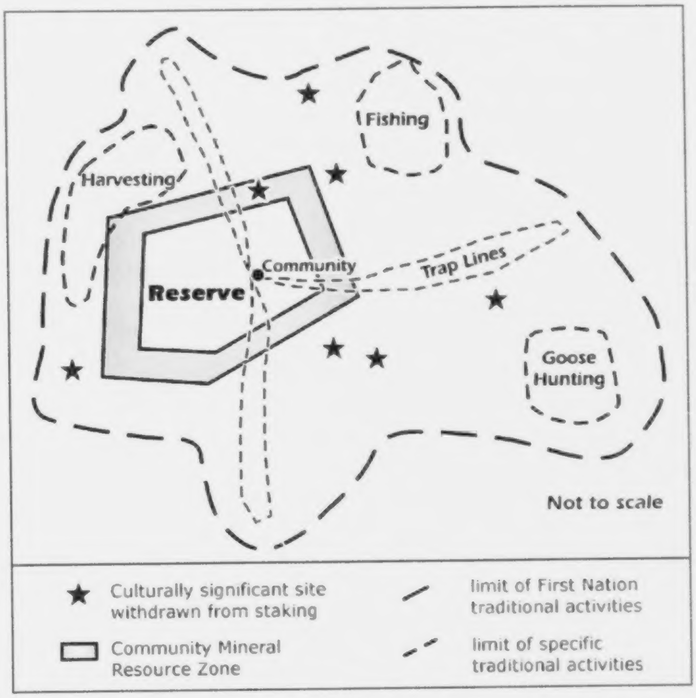
Fishing
Harvesting
Community
Trap Lines
Reserve
Goose Hunting
Not to scale
★ Culturally significant site withdrawn from staking
▭ Community Mineral Resource Zone
limit of First Nation traditional activities
limit of specific traditional activities

Figure 1.1. Schematic diagram illustrating a summary of the "3 Offers".

CURRENT STATUS

Since the "3 Offers" were first made, several First Nations have requested follow-up visits by MNDM staff to further explain different aspects of the offers and to respond to their questions. The Assistant Deputy Minister and senior managers are presently responding to these requests in a pro-active manner by visiting those communities with an interest and providing the opportunity for dialogue and information exchange.

New innovative approaches, such as the "3 Offers" and other communications and relationship-building initiatives presently in progress, are examples of the MNDM's commitment to assisting First Nations to build capacity and understanding of the mining sequence. By doing so, economic development possibilities for Far North communities are enhanced, while, at the same time, the basis for better relationships between exploration and mining companies and First Nations of the Far North is being prepared.

REFERENCES

Mining Lands Section policies, Ministry of Northern Development and Mines

GA 701-3 Withdrawing Land: Aboriginal Culturally Significant Sites in the Far North (http://www.mndm.gov.on.ca/MNDM/MINES/LANDS/policies/gapolicy/ga701-3_e.asp)

GA 701-4 Withdrawing Aboriginal Culturally Significant Sites: Process (http://www.mndm.gov.on.ca/MNDM/MINES/LANDS/policies/gapolicy/ga701-4_e.asp)

LP 201-1 License of Occupation: Community Mineral Resource Zone (http://www.mndm.gov.on.ca/MNDM/MINES/LANDS/policies/lppolicy/lp201-1_e.asp)

LP 201-2 License of Occupation: Process for Community Mineral Resource Zones (http://www.mndm.gov.on.ca/MNDM/MINES/LANDS/policies/lppolicy/lp201-2_e.asp)

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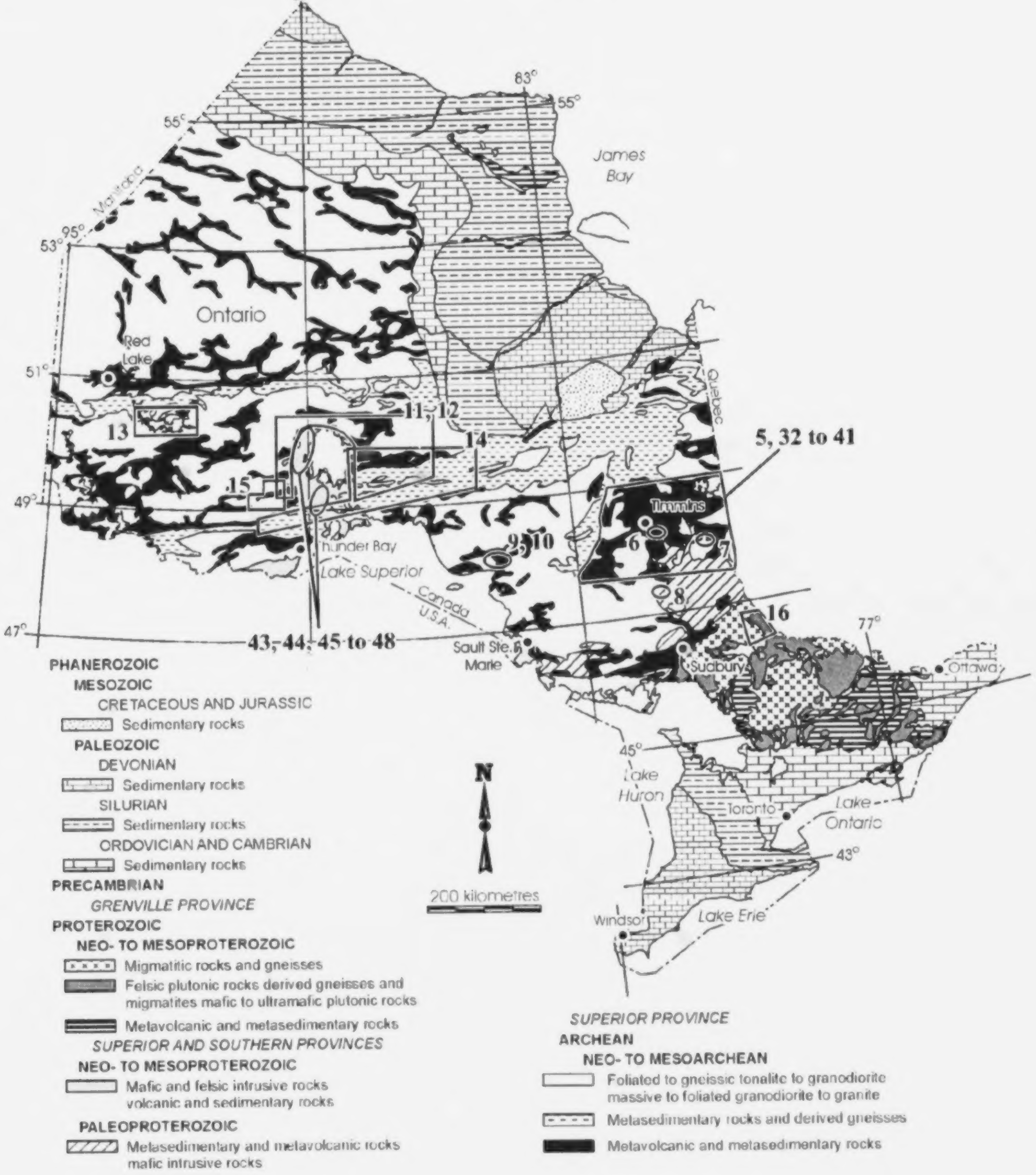
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2. Precambrian Geoscience Section – Program Overview

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GOAL AND RESPONSIBILITY OF THE PRECAMBRIAN GEOSCIENCE SECTION

The goal of Precambrian Geoscience Section (PGS) is to improve the understanding of the Precambrian geology of Ontario and mineral deposit settings and to convey this knowledge to clients through multi-year, multidisciplinary geoscience studies to address critical geological problems, in key geographic areas. These studies may be delivered as part of the PGS core mapping responsibility or through collaborative partnerships with other organizations.

PGS is responsible for

- mapping of Ontario's Precambrian bedrock and understanding of various mineral deposit settings
- regional gravity, magnetic and electromagnetic geophysical data and derivative products in support of the bedrock mapping program.

PROGRAM DIRECTION: STRATEGIC THRUSTS

Core Bedrock Mapping and Geophysics Program

The PGS program is organized into 6 technical or administrative strategic thrusts (Table 2.1). The Strategic Thrusts are derived from the Ministry business goals articulated in the Ministry of Northern Development and Mines (MNDM) business plan. The purpose of PGS Strategic Thrusts is to focus skilled staff and resources in key geological areas or themes, over a period of 3 to 5 years:

- understand the geology and metallogeny of high mineral potential areas in the Superior, Southern and Grenville provinces
- understand and inventory provincial-scale relationships, settings and descriptive data sets of commodities or mineral deposit types currently or of future interest to the mineral exploration industry (e.g., potential diamond-bearing rocks, gold mineralization, rare-element and/or petalite-bearing pegmatites, nickel-copper-platinum group element (PGE) mineralization and volcanogenic massive sulphide mineralization (VMS))
- improve knowledge of, and access to, geophysical information by providing an effective and efficient information management system through the identification, recovery, (re-)formatting, organization and delivery of all available OGS and proprietary geophysical information; provide derivative geophysical products, concepts and ideas, based on those geophysical data, to support the bedrock mapping program; and support of the bedrock mapping program by providing derivative geophysical products, concepts and ideas, based on those geophysical data

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Summary of Field Work and Other Activities 2003,
Ontario Geological Survey, Open File Report 6120, p.2-1 to 2-7.

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- implement program support practices and instruments to address and refine the PGS core program, the human resource strategy, digital data standards, measurement of program results and impact and program management practices
- develop client, stakeholder, and First Nation relationships by: providing a liaison role, representation, or support on behalf of the Mines and Minerals Division, the OGS, and PGS on MNDM or client committees, including the OGS Advisory Board, the OGS Advisory Board Technical Committee, regional client association meetings, inter-Ministry committees, and committees or working groups associated with professional or learned associations

These strategic thrusts are addressed through a series of initiatives, built upon one or more projects (Parker, this volume). The purpose of the strategic thrusts is to focus the skilled staff and resources in key geological areas to address the priorities and needs of the initiative. In addition, PGS participates in several collaborative projects (*see also* Parker, this volume) in order to complement existing PGS staff skills and capacity and to help expand the amount of geoscience data available that describe Ontario.

NEW PROJECTS

During the 2003–2004 fiscal year, the following new technical initiatives will be fully operational and will require resources of the PGS:

- Discover Abitibi (mapping staff are integrated into this inititative and a possible three-dimensional project, in collaboration with MIRARCO, is under discussion);
- Lake Nipigon Region Geoscience Initiative (PGS is conducting the bedrock mapping and assisting with the data integration and analysis in a three-dimensional environment through a partnership with MIRARCO);
- First Nation communication and relationship-building projects are in progress with Eabametoong First Nation (Deputy Minister and Chief signed a formal Cooperation Agreement in December 2002), Marten Falls First Nation, Neskantaga First Nation, and Kasabonika Lake First Nation.

These new projects required different operational, business, and legal models and have taken considerable staff and management time to design, plan, and implement. Other administrative units in MNDM have been very helpful in moving these complex projects forward.

Geoscience Projects

During fiscal year 2003 to 2004, the PGS supported 35 active core projects and 17 active collaborative projects (Parker, this volume).

FIRST NATION DIALOGUE

The Precambrian Geoscience Section continued its dialogue with First Nation communities and related Tribal Councils where there is a common interest in present and future geoscience projects. These discussions involved Treaty 9 First Nation communities.

The purpose of the dialogue is to develop shared understandings of respective needs and expectations related to resource development and geological survey projects. With one First Nation community, the dialogue has culminated in a formal communication agreement.

Table 2.1. Strategic thrusts of the Precambrian Geoscience Section: 2003 to 2004 and beyond.

Strategic Thrust	Thrust Objective	Initiatives To Achieve Thrust	Priority Action
Understand the geology and metallogeny of high mineral potential areas in the Superior, Southern and Grenville provinces	Improve understanding of the tectonic and metallogenic evolution and mineral potential of the Superior, Grenville, and Southern provinces by integration of systematic bedrock mapping, mineral deposit studies, geological and geophysical interpretation and compilation at scales of 1:5000, 1:20 000, 1:50 000, 1:100 000, 1:250 000 and 1:2 000 000	Provincial Initiatives	Provincial Resource Allocation: Undertake bedrock mapping and compilation and augment with mineral deposit data and geophysical interpretation of: • *non-frontier* areas and mining camps at scales of 1:20 000, 1:50 000 and 1:100 000 in the Abitibi greenstone belt; • *non-frontier* areas at scales of 1:20 000 to 1:50 000 in the eastern and western Wabigoon Subprovince ("Ring of Fire"); • *non-frontier* areas at a scale of 1:20 000 (e.g., Wawa and Timmins areas).
		Abitibi Initiative	Abitibi Initiative: • *Discover Abitibi*: In collaboration with Timmins Economic Development Corporation, academia and industry participate in and provide support to the Discover Abitibi project.
		Proterozoic Initiative	Proterozoic Initiative: *a) Lake Nipigon Region Geoscience Initiative:* • Participate in and support the Lake Nipigon Region Geoscience Initiative in collaboration with Ontario Prospectors Association, industry, academia and other government surveys (i.e., Geological Survey of Canada). b) *Sudbury Targeted Geoscience Initiative:* • Participate in and support the Sudbury Targeted Geoscience Initiative in partnership with Geological Survey of Canada and University of Ottawa to improve understanding of geology and controls on nickel-copper-PGE mineralization in the Sudbury Igneous Complex (SIC). c) *Sudbury International Continental Scientific Drilling Program (ICDP) project:* • In partnership with Mineral Exploration Research Centre (MERC), Geological Survey of Canada, industry, and universities, help define the geoscience needs and participate in the design of a geoscience proposal to ICDP to address science and technology gaps that encumber enhanced exploration of the Sudbury region.
		Metallogeny and Geology of Northwest Ontario	Metallogeny and Geology of Northwest Ontario a) *Western Superior NATMAP project:* • In partnership with Geological Survey of Canada (GSC), work to complete and publish the maps and reports for the Western Superior NATMAP Initiative to resolve the distribution of old and young crust and its metallogenic significance. b) *Far North Project (Exposed Sachigo and Precambrian basement project):* • In partnership with GSC, to stimulate exploration and support regional-scale bedrock interpretation of northern Ontario, interpret the geology of the exposed Sachigo and the Precambrian substrate to the James Bay and Hudson Bay lowlands.

Table 2.1. continued

Strategic Thrust	Thrust Objective	Initiatives To Achieve Thrust	Priority Action
Understand and inventory provincial-scale relationships, settings and descriptive data sets of commodities or deposits types	Improve the understanding of, and mineral potential for, rocks that may contain economic concentrations of mineral resources	Provincial-scale metallogenic inventory	a) Document the distribution of, regional settings, and characteristics of • Kimberlite- and kimberlite-like rocks that may host diamonds; • Fractionated pegmatites and related fertile granites that may host rare-metals and petalite in northeastern and southern Ontario; • gold mineralization and associated alteration; • mineralized, intermediate to felsic plutonic systems; • evolved (FI to FIII-type) felsic metavolcanic rocks across the Superior Province. b) Maintain geochronology database for Ontario.
Improve knowledge of, and access to, geophysical information and provide geophysical support to the bedrock mapping program	Integrate regional geophysics into core business bedrock mapping projects	Geophysics and Bedrock Mapping Integration Initiative	• Provide ongoing support of bedrock mapping and compilation projects. • Maintain the Geophysical Atlas containing a graphical index of all available airborne geophysical survey information describing Ontario.
	Improve client awareness of, and access to, all OGS and proprietary geophysical data sets	Geophysics and Rock Properties Data Set Initiative	• Continue the implementation and development of a rock properties database as part of OGS bedrock mapping project, i.e., recover rock density data; magnetic susceptibility data; specific gravity; establish data standards, storage format and plan.
Implement program support practices and instruments to address and refine the PGS core program	Implement human resource strategy by focussing on succession plans for critical positions	Strategic hiring and mentoring initiative to anticipate retirements of staff and loss of corporate and technical knowledge.	Address human resource issues by • Recruiting and training to anticipate staff retirements and knowledge loss.
	Complete Management Board Secretariat (MBS) mandated Program Review of geoscience program	Support and Program Management Practices Initiative.	Complete the MBS-mandated geoscience program review and complete program review for PGS.
		Project and Results Management Initiative	Continue to implement and maintain project management tools and practices and impact assessment practices.
	Continue to implement project management and impact assessment practices	Methods Development and Data Standards Initiative	• Assess solutions for point-of-observation collection and processing of field data and begin developing a new process for collecting and digitizing field observations to streamline the workflow process for producing hard-copy maps and digital data sets and creating a common archival format. • Work with Information & Marketing Services Section and Business Solutions Section to update the OGS publication index metadata and index maps for public distribution. • Apply drafting and GIS functions in support of the PGS mapping program.

Table 2.1. continued

Strategic Thrust	Thrust Objective	Initiatives To Achieve Thrust	Priority Action
Develop client, stakeholder, and First Nation relationships	Ensure external and internal clients and stakeholders are aware of the value of OGS geoscience program and manage client issues	External and internal committees	Client and stakeholder meetings: • Represent Mines and Minerals Division, OGS, and PGS on internal government and external client and stakeholder committees, including the OGS Advisory Board and its Technical Committee. First Nation Communication Projects: • Develop communication and relationship-building projects with Eabametoong First Nation, Neskantaga First Nation, Kasabonika Lake First Nation, and Marten Falls First Nation.
Add-on Geoscience Project: Ontario Mineral Exploration Technology (OMET) Program			
Administrative partnership with Mineral Exploration Research Centre, Laurentian University	a) Techniques to find mineral resources in bedrock beneath conductive or thick overburden b) Methods to "see" through the Paleozoic rocks to explore for mineral resources in the underlying Precambrian rock of the Hudson Bay and James Bay lowlands c) Effective ways to utilize Ontario's Quaternary geology to explore for mineral resources buried in the bedrock		Delivery by OMET Program Office, Mineral Exploration Research Centre, Laurentian University (Rayner and Fyon, this volume).

PROJECT PLANNING, MANAGEMENT AND CONSULTATION PROCESS

To plan and deliver 52 active geoscience projects, delivered by core staff and in collaboration with our partners, PGS management and staff continued to refine the planning and project management processes and practices. Information required to describe projects, monitor and adjust progress, and assess their impact on the minerals industry is collected and analyzed to assess if program goals are met (e.g., Churchill and Fyon 1999; Churchill et al. 2000; Churchill, Fyon and Baker 2001).

To formulate and discuss project plans for summer of 2003 and to begin development of summer 2004 project plans, PGS staff were involved in several consultations with regional client associations:

1. October 2002: Ontario Geological Survey Advisory Board – annual meeting
2. October 2002: Southern Ontario Prospectors Association, Tweed
3. February 2003: Joint meeting with Northern Prospectors Association and Porcupine Prospectors and Developers Association in Matheson
4. April 2003: Ontario Geological Survey Advisory Board – OGS program review

ADD-ON PROGRAMS

PGS staff collaborated with other OGS staff to manage, deliver, or participate in 3 significant add-on geoscience programs:

- Ontario Mineral Exploration Technologies Program (Rayner, Lafleur-Roy and Fyon, this volume)
- Discover Abitibi (PGS core business mapping staff are integrated into this project)
- Lake Nipigon Region Geoscience Initiative (PGS is conducting the bedrock mapping and assisting with the data integration, under contract to or in collaboration with Ontario Prospectors Association. PGS and MIRARCO are collaborating on a three- and four-dimensional project to organize, visualize, and analyse the geoscience data using the VRLaboratory)

INTER-JURISDICTIONAL AND COMMITTEE REPRESENTATION

During the 2003 to 2004 fiscal year, PGS staff represented the Ontario Geological Survey on several committees and associations, including

1. Committee of Provincial Geologists
2. National Geological Surveys Committee
3. Mineral Exploration Research Centre, Laurentian University, Board of Directors
4. Canadian Mineral Industry Research Organization (CAMIRO) Exploration Division, Board of Directors
5. Member, Lake Nipigon Region Geoscience Initiative Science Advisory Committee
6. Commissioner, North American Commission on Stratigraphic Nomenclature
7. Northern Ontario OARS (Ontario Association of Remote Sensing) Regional Councillor
8. Adjunct professors at Carleton University, University of Ottawa, or Laurentian University
9. Lead the MNDM Quality Assessment Team
10. MNDM Health and Safety Committee

ONTARIO GEOLOGICAL SURVEY ADVISORY BOARD

The Ontario Geological Survey Advisory Board (OGSAB) provides client-focussed, expert strategic advice and guidance to the Minister of Northern Development and Mines on

- issues facing, and that must be addressed by, the minerals industry
- the needs and priorities of the minerals industry; and
- major program priorities of the OGS to guide OGS in meeting its core business of providing the province's geological data and mapping function

PGS provides executive support to the OGSAB and its geoscience Technical Committee. During the past year, the OGSAB met twice. At one of these meetings, the OGSAB received the report on the OGS geoscience program that was prepared by the OGSAB Technical Committee.

NEW FACES TO THE PRECAMBRIAN GEOSCIENCE SECTION

M. Houlé joined the PGS in spring 2003 as a Geoscientist.

S. McIlraith competed for and won the position as PGS Applicationist.

S. Josey competed for and won the position as PGS Geological Assistant.

C.A. MacDonald accepted a contract position with the PGS to conduct bedrock mapping in the Lake Nipigon region, under the auspices of the Lake Nipigon Region Geoscience Initiative.

J.B. Selway accepted a contract position with the PGS to conduct field work on fertile peraluminous granites and related rare-element pegmatite mineralization in Ontario under the leadership of F.W. Breaks. J.B. Selway left PGS in the fall of 2003.

E. Roy returned to PGS in September 2002, accepting a contract as PGS Drafter.

REFERENCES

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Churchill, L.L., Roque, J., Baker, C.L. and Fyon, J.A. 2000. Preliminary impact analysis of Operation Treasure Hunt surveys; *in* Summary of Field Work and Other Activities 2000, Ontario Geological Survey, Open File Report 6032, p.48-1 to 48-10.

3. Precambrian Geoscience Section—Project Overview

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INTRODUCTION

The fundamental core functions of Precambrian Geoscience Section (PGS) projects are to

1. provide geoscience maps, reports, data, technical talks and posters, new concepts and ideas and client consultations; and
2. provide regional airborne magnetic and electromagnetic geophysical data, derivative products, and concepts and ideas based on those geophysical data to support the bedrock mapping program.

In 2003, the PGS produced 10 preliminary maps, 9 open file reports, 10 miscellaneous data releases (MRDs) and 4 final maps. More than 150 airborne geophysical hard-copy maps and 50 airborne geophysical digital data sets were released in 2003. PGS staff, at various geoscience forums throughout the year, presented approximately 32 technical talks and 28 posters.

The program direction and strategic thrusts (Fyon, this volume) of PGS address the mission statement and core business of the Ministry of Northern Development and Mines. Strategic thrusts are achieved through a variety of initiatives that are built upon one or more projects (Table 3.1). Therefore, project development, selection, planning and implementation are based on the strategic thrusts and initiatives in order to achieve alignment of individual projects with Ministry priorities.

The PGS presently has 35 active core projects (*see* Table 3.1). The PGS is also involved in 17 active collaborative project agreements in various stages of completion and with a variety of partners (Table 3.2). The collaborative project agreements include 11 active projects with the Geological Survey of Canada (*see* Table 3.2). In all, the PGS supported 52 geoscience projects during the 2003–2004 fiscal year.

For the first time, the PGS bid on a Request For Proposal issued by the Ontario Prospectors Association to conduct a two-year bedrock mapping project in the western Nipigon Embayment as part of the Lake Nipigon Region Geoscience Initiative (LNRGI). The PGS bid was successful, contract staff were hired and bedrock mapping began in July 2003 (Rayner, Lane and Easton, this volume; Hart and MacDonald, this volume).

PRECAMBRIAN GEOSCIENCE SECTION INITIATIVES

PGS initiatives are based on geographic or functional groupings and are made up of 1) team initiatives (i.e., Abitibi initiative) consisting of individual projects that are designed to meet an overall goal; 2) inter-jurisdictional team initiatives, such as Western Superior NATMAP, that consist of individual and joint Ontario Geological Survey (OGS) and Geological Survey of Canada (GSC) projects that are also designed to meet an overall goal or objective; and 3) individual, focussed projects. The major initiatives of the PGS are subdivided into 6 broad categories outlined below and in Table 3.1.

Summary of Field Work and Other Activities 2003,
Ontario Geological Survey, Open File Report 6120, p.3-1 to 3-11.

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Table 3.1. Precambrian Geoscience Section core projects, 2003–2004.

Initiative	Project	Project Goal	Project Status
Abitibi Initiative	Abitibi compilation – 1:250 000 sheet	Complete 1:250 000 scale compilation of Abitibi greenstone belt	On schedule for completion in 2004.
	Discover Abitibi	Participation in Technical Committee	Ongoing.
	Regional mapping in the Matachewan area–Eby and Otto townships	Map 6 townships and compile geology in Matachewan area	Second year completed. Eby and Otto townships mapped at 1:20 000. Maps due in 2004.
	Shining Tree synoptic report	Complete 1:50 000 scale compilation map and synoptic report	1:50 000 map published in 2003. Report in preparation for publication in 2004.
	Bedrock mapping in the South Shining Tree area	Complete 1:50 000 scale bedrock mapping of 12 townships	Maps due for release in 2003.
	Bedrock mapping in the Timmins Area–Shaw, Eldorado, Adams townships	1:20 000 scale bedrock mapping; volcanology and economic potential of komatiitic rocks	Maps to be published in April 2004; komatiite study is ongoing until 2005.
	Synthesis of Archean geology and diamond-bearing rocks in the Michipicoten greenstone belt	1:20 000 scale bedrock mapping of Menzies Township. Possible mapping in Lalibert, Musquash and Leclaire townships over the next 2 years	Bedrock mapping of Menzies Township completed. Map on schedule for publication in April 2004.
Proterozoic Initiative	Lake Nipigon Region Geoscience Initiative	Staff participation in Implementation and Science Advisory Committees	Ongoing.
	Bedrock mapping of southern Nipigon Embayment	1:50 000 scale bedrock mapping over 2 years	First year of mapping completed. Map and report due to be published in April 2004.
	Geology and mineral potential of Henry and Loughrin townships	1:20 000 scale bedrock mapping; synoptic report of River Valley area	Mapping completed in 2003. Map to be published in 2004. Synoptic report to be published in 2003–2004.
	Geology and mineral potential of eastern Tomiko terrane, Grenville Province	1:50 000 scale bedrock mapping of 4 1:50 000 NTS sheets	Mapping completed. Maps due to be published in 2004.
	Geological compilation of the Georgian Bay area, Grenville Province	Digitize and publish 1:50 000 scale maps by N. Culshaw	Digitizing complete. Maps on schedule for publication in 2004.

Table 3.1. continued

Initiative	**Project**	**Project Goal**	**Project Status**
Metallogeny and Geology of Northwest Ontario	Geology of the Wabigoon area	Map Wabigoon–Dinorwic lakes area at 1:20 000 and 1:50 000 scales	Project on-hold for 2003.
	Geology of central Wabigoon Subprovince: geology and mineral potential of the Lac des Iles area	1:50 000 scale bedrock mapping of 3 1:50 000 NTS sheets	Bedrock mapping completed. Maps to be released in 2004.
Provincial-scale Metallogenic Inventory Initiative	Distribution of potentially VMS-productive felsic metavolcanic rocks	Compile locations of FI, FII and FIII-type rhyolites across Ontario	Ongoing compilation.
	Characteristics of mineralized intermediate to felsic plutonic systems	Gather/compile information on barren and mineralized felsic plutons across Ontario	Ongoing compilation.
	Update and maintain geochronology database	Maintain up-to-date geochronology database for Ontario	Ongoing. Last published in 2001.
	Distribution and documentation of provincial-scale rare-element pegmatite mineralization	Document fertile peraluminous granites and related rare-element pegmatite mineralization in Ontario	Ongoing documentation of pegmatites in Quetico Subprovince. Results to be published in 2004–2005.
Provincial-scale Diamond Assessment	Study of diamond occurrences and kimberlite indicator minerals	Detailed petrographic study of Archean diamond-bearing rocks	Ongoing. Report to be published in 2004.
Geophysics and Bedrock Mapping Integration Initiative	Fort Hope–New South Wales methodology	Apply NSW methodology to integrate geophysics with bedrock mapping	Delayed. Will progress in 2004–2005.
	Geophysics integration with bedrock mapping projects	Integrate geophysics into the PGS bedrock mapping program	Ongoing.
	Geophysical training through interpretation of selected greenstone belts	Providing geophysical training to geoscientist to assist geophysicist	Ongoing.
Geophysics and Rock Properties Data Set Initiative	Rock properties project	Collect and archive rock properties data	Ongoing.
	Geophysical data conversion	Reformat geophysical data from Centurion format	Reformatted data released in 2003.
	Levelling and reformatting projects	Level airborne geophysical data to Ontario master grid	12 surveys completed and released with more to be released in December 2003.
	Operation Treasure Hunt – data management	Manage and QC all OTH data	Completion in August 2003.
	Fort Hope geophysical survey	Essentially complete with some final data processing	Airborne gamma ray spectrometry data scheduled to be released in 2003–2004.

Table 3.1. continued

Initiative	**Project**	**Project Goal**	**Project Status**
Support and Program Management Practices Initiative	Improving OGS archives	Improve archives database and archiving processes	Ongoing.
	PGS Learning Plan – administrative project	Develop and commit to learning plan for PGS	Ongoing. Plan established for 2003–2004.
Strategic Hiring and Mentoring Initiative	Managing loss of staff, corporate and technical knowledge	Hire and train "strategically" to anticipate staff retirements	Ongoing.
Project and Results Management Initiative	Impact analysis of PGS mapping program	Analyze impact of geoscience projects on economy of Ontario and mineral industry	Ongoing.
Methods Development and Data Standards Initiative	Integrated solution for field data collection and processing	Establish new methods for digital collection of geological data in the field; development of data model for mapping projects	Ongoing. Testing of new methods during 2003.
	Digital map standards throughout Ontario	Standardize digital map standards	Suspended.
	Attributed maps (Smart Maps) synoptic mapping – Abitibi Subprovince & elsewhere	Release maps with database attached	Suspended.
External and internal committees: OGS Advisory Board; First Nations	Ongoing development of relationships and exchange of information with clients, stakeholders and First Nations	Ensure external and internal clients and stakeholders are aware of the value of the OGS geoscience program	Ongoing.

Table 3.2. Precambrian Geoscience Section collaborative projects, 2003–2004.

Initiative	Project	Project Collaborator (s)	Project Progress
Abitibi Initiative	Discover Abitibi – Greenstone Architecture Project	MERC–Laurentian University; University of Ottawa; University of Wisconsin – Oshkosh; Geological Survey of Canada; Consultants	First year of field work completed.
Proterozoic Initiative	Midcontinent Rift compilation	United States Geological Survey; Minnesota Geological Survey; McAlester College; Wisconsin Geological and Natural History Survey	Ongoing. Completion date in 2004.
	Paleomagnetic discrimination of Proterozoic dike swarms east of Lake Nipigon	University of Toronto	Second year of project. Ongoing.
Provincial-scale Diamond Assessment	Petrogenesis of Archean diamondiferous lamprophyres and sssociated Breccia	University of Sydney, New South Wales, Australia; Laboratório de Geologia Isotópica, Brazil	Ongoing through 2003–2004.
Collaborative Projects with GSC: Sudbury Targeted Geoscience Initiative	Structural geology of southwestern Sudbury Igneous Complex (Trill, Drury, Fairbank and Denison townships)	University of Ottawa; Geological Survey of Canada	Final year for TGI. Final report and map to be published in December 2003.
Collaborative Projects with the GSC: Far North Initiative	Reprocessing and interpretation of ODM–GSC geophysics of exposed Archean in Sachigo Subprovince	Geological Survey of Canada	Ongoing, plan to complete in 2004 or 2005.
	Reprocessing and interpretation of ODM–GSC geophysics of Proterozoic substrate, James Bay Lowlands	Geological Survey of Canada	Ongoing, plan to complete in 2004.
	Reprocessing and interpretation of ODM–GSC geophysics of Archean substrate, Hudson Bay Lowlands	Geological Survey of Canada	Ongoing, plan to complete in 2004.
	Discrimination of Archean tectonic domains across northwestern Ontario	Geological Survey of Canada; DeBeers Canada Exploration Inc.; GEMOC–Macquarie University, New South Wales, Australia	Commenced in 2003.

Table 3.2. Precambrian Geoscience Section collaborative projects, 2003–2004.

Initiative	Project	Project Collaborator (s)	Project Progress
Collaborative Projects with the Geological Survey of Canada (GSC): Western Superior NATMAP and Lithoprobe Initiatives	Structural/stratigraphic, metallogenic Synthesis Red Lake Greenstone Belt	Geological Survey of Canada	1:50 000 scale map to be completed by GSC in 2003–2004.
	Geology of East Sachigo Subprovince	Geological Survey of Canada	1:250 000 scale map to be completed by OGS in 2004.
	Geology of East Uchi Subprovince	Geological Survey of Canada	1:250 000 scale map to be completed by GSC in 2003–2004.
	Regional metallogeny of northwest Superior Province	Geological Survey of Canada	Ongoing. Metallogenic maps to be completed by OGS in 2004–2005.
Western Superior Lithoprobe Initiative	Western Superior Lithoprobe Transects – reflection seismic transect routes	Geological Survey of Canada and various universities	Ongoing.
Metallogeny and Geology of Northwest Ontario	Winnipeg River Project	GEMOC–Macquarie University, New South Wales, Australia; University of Toronto; McMaster University	Completed 2003.
	Red Lake Metamorphic Study	P.H. Thompson Geological Consulting	Completed. Publication of report and map in December 2003.
Geophysics	Aur Resources airborne geophysical data exchange (James Bay Lowlands)	Aur Resources Ltd., G. Teed Consulting Services	Data is being prepared for release in spring 2005.

1. Initiatives that involve collaborative project agreements with the Geological Survey of Canada :
   - Western Superior NATMAP and Lithoprobe mainly focussed in north and northwest Ontario;
   - Targeted Geoscience Initiative focussed on the Sudbury Igneous Complex (SIC);
   - The Far North Initiative in the Hudson and James Bay lowlands.

2. Initiatives involving provincial-scale metallogenic compilation and inventory studies:
   - documentation of pegmatite-hosted mineralization;
   - documentation of magmatic nickel-copper-platinum group element (PGE) metallogeny in Ontario that includes projects such as the platinum-group element mineralization and mafic to ultramafic intrusion compilation and inventory (collaborative project agreements between OGS and the Mineral Exploration Research Centre (MERC, Laurentian University) and GSC, respectively);
   - diamond assessment;
   - inventories of various tectonic settings relevant to mineral exploration.

3. Initiatives based on geographic area:
   - Abitibi initiative;
   - metallogeny and geology of northwest Ontario;
   - Proterozoic initiative.

4. Initiatives involving program support of the PGS program:
   - support and program management practices;
   - project and results management;
   - methods development and data standards;
   - strategic hiring and mentoring.

5. Initiatives involving geophysical projects:
   - geophysics and bedrock mapping integration initiative
   - geophysics and rock properties data set initiative.

6. Initiatives that develop and manage client, stakeholder and First Nation relationships:
   - external and internal committees;
   - OGS Advisory Board and its Technical Committee and regional associations;
   - developing relationships and exchanging technical and administrative information with First Nation communities.

Collaborative Projects with the Geological Survey of Canada

Field work for the Western Superior NATMAP initiative was completed in 2000. In 2003, PGS continued work on the 1:250 000 scale, East Sachigo bedrock compilation map for release in 2004. PGS is also responsible for completing a series of 6 metallogenic compilation maps building upon the bedrock compilation maps. The GSC is responsible for delivering the 1:250 000 scale East Uchi sheet and the 1:50 000 scale Red Lake sheet in 2003 or early 2004. Interpretation of the Lithoprobe reflection seismic transect routes across the western Superior Province continued in 2003 under the Western Superior Lithoprobe initiative.

The Sudbury Targeted Geoscience Initiative (TGI) was completed in 2003. The Sudbury TGI was a three-year program (2000–2003) designed to gain a better understanding of the setting and processes involved in forming the large nickel-copper-PGE deposits of the Sudbury Igneous Complex (Ames 2002). The initiative consisted of 4 collaborative projects that include the Geological Survey of Canada, the Ontario Geological Survey, mineral industry and several universities. One of these projects was an investigation of the lithological and structural controls on mineralization in the Sudbury Igneous Complex and in its immediate footwall (Dubois and Benn 2003). This two-year project was completed in 2003 and was supported under an Ontario Geological Survey–University of Ottawa Collaborative Project Agreement, involved bedrock mapping in contiguous parts of Trill, Drury, Fairbank and Denison townships in the southwest part of the Sudbury Igneous Complex. A final report from this project will be released in December 2003.

G.M. Stott continued work on the geological interpretation of the Archean and Proterozoic substrate below the Phanerozoic cover of the James Bay and Hudson Bay lowlands and the exposed Archean in the Sachigo Subprovince as part of a Ontario Geological Survey–Geological Survey of Canada Collaborative Project Agreement. The interpretation is using reprocessed ODM–GSC airborne geophysical data and proprietary geophysical data purchased under the Operation Treasure Hunt initiative. The project will 1) compile geoscience data for the James Bay and Hudson Bay lowlands in order to provide an interpretation of bedrock features beneath the Phanerozoic cover; 2) produce 3, 1:500 000 scale geological maps in hard-copy and digital formats.

A project was initiated in 2003 to discriminate between Archean tectonic domains across northwestern Ontario as part of the lowlands work described above. The project is a collaboration between the Ontario Geological Survey, DeBeers Canada Exploration Inc., Geological Survey of Canada and GEMOC–Macquarie University, New South Wales, Australia. The project consists of sampling outcrops and diamond-drill core for geochronology and neodymium, hafnium isotopic characterization of felsic intrusive rocks. The results will be used to assist in subdividing the most northern part of the Superior Province in Ontario into tectonic domains of contrasting age and tectonic development.

Provincial-Scale Metallogenic Compilation and Inventory Studies

The PGS continued a rare-element pegmatite characterization project to study rare-element mineralization. This is a continuation of an ambitious project, originally supported under the Operation Treasure Hunt initiative, to compile, document and study fertile peraluminous granites and related rare-element pegmatites across Ontario (Breaks, Selway and Tindle 2003). The purpose of this project is the preparation of a comprehensive field, chemical, mineralogical and geochronological database for fertile granites and associated rare-element pegmatites for the entire Superior Province of Ontario. Field work in 2003 focussed on the Quetico Subprovince in northwestern Ontario. Once again, several new rare-element exploration targets were identified in the Barbara–Gatherin rbaro lakes area southeast of Lake Nipigon (Breaks, Selway and Tindle, this volume).

Another ambitious project, supported by Operation Treasure Hunt, was initiated in 2001 to determine the potential for platinum-group element mineralization in mafic to ultramafic intrusions across Ontario (Vaillancourt et al. 2001). This project concluded in 2003 with the publication of a final report and digital data release (Vaillancourt et al. 2003).

Ongoing, multi-year, province-scale projects that fall under the initiative to create inventories of various tectonic settings relevant to mineral exploraton are 1) the documentation and distribution of FI, FII and FIII-type, potentially volcanogenic massive sulphide deposit (VMS)-productive felsic metavolcanic rocks; 2) characteristics of mineralized intermediate to felsic plutonic systems; and 3) update and maintain the geochronology database for Ontario. Two projects under the provincial-scale diamond assessment initiative are described below.

Initiatives Based on Geographic Area

The Abitibi initiative includes 7 core business, multi-year, mapping projects (*see* Table 3.1), including the 1:250 000 scale compilation of the Abitibi greenstone belt (Ayer, this volume), as well as 2 collaborative project agreements (*see* Table 3.2) (Ayer, this volume). J.A. Ayer is the Precambrian Geoscience Section's representative on the Technical Committee of the Discover Abitibi Initiative. This is a community-based and directed program designed to stimulate exploration for, and eventual development of, mineral deposits within the Abitibi greenstone belt of northeastern Ontario. The program will be achieved through the co-operation and collaboration between Federal, Provincial and Municipal governments and private-sector partners.

The Discover Abitibi Initiative includes several new geophysical surveys and a new mapping and metallogenic research project identified as the Greenstone Architecture Project (Ayer, Thurston et al., this volume). The project was awarded to the Mineral Exploration Research Centre (MERC)–Laurentian University and involves an international multi-disciplinary science team. J.A. Ayer shares science leadership and project co-ordination with MERC–Laurentian University staff for the Greenstone Architecture Project. The major goal of the project is to obtain an improved understanding of the controls on base metal and gold mineralization in a number of key areas with good economic potential in northeastern Ontario. Several subprojects in the Greenstone Architecture Project are described in detail in a separate Discover Abitibi section of this volume (*see* articles under the heading "Discover Abitibi Initiative").

A new 1:20 000 scale bedrock mapping project was initiated in Menzies Township in the Michipicoten greenstone belt at Wawa (Vaillancourt, Wilson and Dessureau, this volume). The purpose of the project is to map a township that was never detail mapped by the Ontario Geological Survey and to document the geological environment of diamond-bearing Archean breccias and lamprophyres. Other projects that are associated with the bedrock mapping project in Menzies Township and are also part of the provincial-scale diamond assessment initiative are

1. a study of the characteristics of diamonds and the mineralogy and thermobarometry of diamond-bearing rocks in the Wawa area was started in 2003 by Denver Stone and Linda Semenyna (Geoscience Laboratories, Geoservices Centre, Sudbury); and
2. a study of the timing and petrogenesis of diamondiferous lamprophyres in the Michipicoten and Abitibi greenstone belts, which is a collaborative project agreement between the Ontario Geological Survey, the University of Sydney (Australia) and the Laboratório de Geologia Isotópica, Universidade Federal do Rio Grande do Sul, Porto Alegre, Brazil was started in 2003 (Ayer, Conceição et al., this volume).

The geology and metallogeny of northwest Ontario initiative currently includes 2 core projects 1) geological mapping in the Dryden–Wabigoon area, which was suspended for 2003; and 2) bedrock mapping in the Lac des Iles area of the central Wabigoon Subprovince (Stone et al., this volume). Two collaborative project agreements under this initiative include

1. a study of the geochemistry and neodymium isotopic character of granitoid rocks in the Lac Seul region of the Winnipeg River Subprovince (Tomlinson and Dickin, this volume), which is a collaborative project agreement between the Ontario Geological Survey and GEMCO–Macquarie University, New South Wales; and
2. a metamorphic study in the Red Lake greenstone belt, which is a collaborative project agreement between the Ontario Geological Survey, Peter H. Thompson and Placer Dome Inc.

The purpose of the Red Lake metamorphic study is to map the various metamorphic zones within the Red Lake greenstone belt using several hundred thin sections from the OGS and GSC archives. The goal of this project is to determine the relationship between metamorphic grade and gold mineralization and to develop new gold exploration targets in the greenstone belt. The results of this project will be released in December 2003.

The Proterozoic initiative includes several projects, such as

1. completion of bedrock mapping in Henry and Loughrin townships, west of the River Valley area (Easton 2002);
2. geological compilation (1:50 000 scale) of the Georgian Bay area, Grenville Province;
3. 1:50 000 scale reconnaissance study of the geology and mineral potential of the eastern Tomiko terrane, Grenville Province (Easton, this volume);
4. continuation of the paleomagnetic discrimination of Proterozoic dike swarms in the vicinity of Lake Nipigon, which is an Ontario Geological Survey–University of Toronto Collaborative Project Agreement (Halls and Stott, this volume; Davis and Stott, this volume); and
5. a continuation of a compilation of the geology of the Mid-Continent Rift conducted in collaboration with the United States Geological Survey, the Minnesota Geological Survey and the Wisconsin Geological and Natural History Survey.

The Proterozoic initiative also includes the Lake Nipigon Region Geoscience Initiative (LNRGI). LNRGI is operated by the Ontario Prospectors Association (OPA) and funded through an agreement with the Northern Ontario Heritage Fund Corporation (Rayner, Lane and Easton, this volume). LNRGI involves partnerships with the private sector, Lakehead University and several communities in the Lake Nipigon area. The aim of the initiative is to attract mineral industry investment to the Lake Nipigon area (Rayner, Lane and Easton, this volume) through bedrock mapping, airborne and ground geophysical surveys and targeted surficial geochemical and geochronological studies.

Bedrock mapping of the western Nipigon Embayment, at a scale of 1:50 000, will be completed by March 2005 (*see* Figure 43.1 in Rayner, Lane and Easton, this volume). The southern part of the Nipigon Embayment will be mapped by the PGS as part of its commitment of in-kind support to the LNRGI (Hart and MacDonald, this volume). Mapping of the northern and central parts of the western Nipigon Embayment is conducted under a contract agreement between the Ontario Geological Survey and the OPA for the LNRGI (Hart and MacDonald, this volume). These mapping projects include interpretation of igneous petrogenesis; stratigraphic analysis; construction of geological cross-sections; collection of rock properties data (i.e., magnetic susceptibility, specific gravity); integration of newly acquired airborne magnetic and gamma-ray geophysical data, as well as ground geophysical gravity data; newly acquired geochronological data; and re-logging of existing diamond-drill core. This work is conducted in collaboration with staff and MSc students at Lakehead University (Kissin, this volume; Metsaranta, Fralick and Rogala, this volume; Richardson, Heggie and Hollings, this volume; Heggie and Hollings, this volume). LNRGI will generate new geoscience data and ideas for the Lake Nipigon area to understand the geological and metallogenic evolution of the region and to stimulate mineral exploration for a variety of mineral deposit types including magmatic nickel-copper-platinum group element mineralization and possible Olympic Dam-type iron-copper-uranium-gold mineralization.

Initiatives Involving Geophysical Projects

Several geophysical projects and activities were conducted under the geophysics and rock properties data set initiative and are described in more detail in Rainsford, Muir and Madon (this volume). Integration of geophysics into the bedrock mapping projects continues with many geoscientists routinely using hand-held magnetic susceptibility meters during mapping, as well as a variety of geophysical data and derived products for interpretation.

Technical support is provided to the Discover Abitibi and LNRGI initiatives as part of in-kind support by the PGS. Ongoing assistance with the publication of digital data sets, from recently flown airborne geophysical surveys, and the integration of geophysical data into the Greenstone Architecture Project, is provided to Discover Abitibi. Participation in the LNRGI included the specifications for a 49 000 km magnetic and gamma-ray spectrometer survey and a 3600 station ground gravity survey encompassing the western Nipigon Embayment (*see* Figure 43.1 in Rayner, Lane and Easton, this volume). The geophysical surveys are augmented with magnetic susceptibility and density data collected as part of the mapping program.

Basic geophysical training for use by prospectors was delivered to the Eabametoong and Marten Falls First Nations communities in advance of the Fort Hope airborne geophysical survey releases. Presentations, on the application of regional-scale geophysics for gold exploration, were given at gold exploration workshops at the Northwest and Northeast Ontario Mines and Minerals symposia in April. Other activities have included providing assistance with display development to the newly opened Dynamic Earth geoscience centre in Sudbury; and the acquisition of archived airborne geophysical data for eventual public release.

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4. Building Relationships and Improving Communications with First Nation Communities—An Operational Approach

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INTRODUCTION

The Ontario Geological Survey (OGS) develops and maintains strategic relationships with a wide range of clients and stakeholders, including the mineral resource industry, academia, other governments, Conservation Authorities, and First Nation communities and organizations. The OGS communication and relationship-building practices are aligned with the business objective of Ministry of Northern Development and Mines (MNDM) to create an attractive business climate for mineral investment in Ontario.

For the past several years, OGS focussed on building communication practices and relationships with several remote and road-access First Nation communities, Tribal organizations, Treaty organizations, and First Nation business agencies. Some of these efforts are taking place in, but are not limited to, First Nation communities located in northwestern Ontario.

In this paper, we describe a range of pragmatic communication and relationship-building practices developed during several pilot OGS projects. The OGS efforts complement other MNDM communication efforts (see Gammon and Owsiacki, this volume). It is possible to define processes and supporting practices that meet the communication needs of individual First Nation communities by investing in meaningful and pragmatic communication and relationship building. During the development of the more comprehensive communication and relationship-building practices, we communicated with, learned from, and built upon the experiences of many other provincial, national, and international practitioners. Other parties may find value in the OGS practices; however, we have learned there is not a single set of practices that work in all situations, for all First Nation communities.

COMMUNICATION AND RELATIONSHIP BUILDING: OGS MEANING, INTENT, AND PRINCIPLES

We define "communication" as the process of exchanging knowledge and information in person and through other means in an open and principled way, to arrive at a shared understanding of each other, of each other's cultures, and of each other's interests, function and intents.

The OGS is developing a principle-based approach to determine an appropriate communication technique and to establish mutually beneficial relationships with First Nation people and their communities (Table 4.1).

Summary of Field Work and Other Activities 2003, Ontario Geological Survey, Open File Report 6120, p.4-1 to 4-10.

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Table 4.1. Principles that guide communication and relationship building between the Ontario Geological Survey and First Nations.

Theme	**Principle**
OGS Program Planning	The OGS endeavours to communicate, where appropriate, with First Nation peoples in the early stages of project and program development to identify and address respective issues.
Awareness Through Communication	The OGS • communicates and develops relationships based on mutual respect and trust, open and frank sharing of information and ideas, and works to achieve shared understandings • acknowledges there is much to learn and gain from the diverse cultures of the First Nation people; hence, OGS provides cross-cultural awareness and guidance to its employees to help them understand and work more effectively with First Nation people • will provide or facilitate prospector training to, and exchange information with, First Nation people in order to increase First Nation peoples' awareness of the OGS, MNDM, and mineral industry businesses and practices, about the science of geology, and about economic development choices related to the mineral industry • commits to listen and communicate with First Nation people about events, issues and other matters of mutual interest • will communicate and co-operate with other provincial and federal ministries on First Nation matters of mutual interest • will participate in innovative communication and relationship-building initiatives to enhance mutual understanding of mineral resources
Impact of OGS Projects	The OGS endeavors to • deliver its projects in an environmentally responsible way respecting First Nation cultural and spiritual values • maximize the positive impacts and mitigate the negative impacts on First Nation communities for existing and future OGS projects through open and honest communication
Economic Development	When planning new geological mapping projects, OGS will • encourage First Nation peoples to take advantage of economic, social and other opportunities related to, or stimulated by, the new mapping projects • co-operate with First Nation peoples, private sector and educational institutions to recommend educational initiatives that help build First Nation capacity and technical skills needed to understand the nature of the mapping project

COMMUNICATION AND RELATIONSHIP BUILDING: THE BUSINESS BENEFITS

Communication and relationship building makes good business sense. It is our experience that business risk can be managed with more certainty and operational opportunities established only with investment in communication and relationship-building practices. The benefits include

- Reduced misunderstandings and reduced confrontation: As a result of improved communication, First Nation communities and OGS develop an improved understanding of respective roles, functions, decision-making processes, values, cultural perspectives, expectations, and concerns. Emerging issues and misunderstandings are discussed immediately, which helps to avoid confrontation.
- Communication partnership projects: As the operational climate improves, discussions focus on the establishment of communication partnership projects designed to effectively exchange information with the community, not just Chief and Council. These communication partnership projects may include the hiring of community leaders to constantly exchange information between OGS and the community. Key communication pieces, such as "story boards" and a glossary of words and phrases, are jointly developed to ensure a shared understanding of the meaning. We attempt to use community members to translate the key pieces from English into the local native language dialect, phonetics, and syllabics. We attempt to encourage school children to illustrate the communication pieces. Communication pieces developed under the auspices of the communication partnership project are jointly owned. The needs of both the OGS and the First Nation community are met and the community has "ownership" and meaningful involvement in the process and the products.
- New knowledge and values: Improved communication and relationships with First Nation peoples brings new knowledge and values into the OGS. This insight helps OGS staff understand the First Nation view of the land, the value of traditional knowledge in planning and inventory functions, and issues to consider during the formulation of strategies and tactics for sustainable development.
- Consistent OGS decision making: OGS decision making is more likely to be consistent when a set of practices is followed. Consistent OGS decision making is important to ensure fair and equitable treatment of all OGS clients and stakeholders.
- Improved operational climate: Without communication, the risk of confrontation increases, project delays are likely, project costs escalate, political risk increases, and public funds may be put at risk through premature project termination. Risk of project cost overruns increases and the risk of project cancellation increases with loss of initial project investment. As the mutual understanding improves and as confrontation is replaced by communication, the OGS operational climate improves. The improved operational climate may extend beyond OGS to improve the relationship between First Nation community and mineral industry companies working close to the First Nation community.
- Community decisions about economic development options: An informed and knowledgeable community is able to weigh and choose economic development options that meet community needs. Without that knowledge gained through communication, communities are more likely to pursue confrontational tactics.
- Foundation to address more controversial issues: Communication and relationship building are the foundation for improved mutual understanding, respect and trust. Only with a strong foundation in place is it possible to begin to address more controversial issues.

The OGS efforts to improve communication with First Nation communities through communication and relationship building are developed and implemented at an operational level to facilitate the delivery of the present OGS geoscience program. These OGS efforts also lay a foundation for the future OGS initiatives. The foundation for OGS economic development initiatives is a strong relationship built on open, frank and meaningful communication.

FIRST NATION COMMUNICATION MODEL

We learned that community engagement is important to ensure successful communication. Community engagement takes place in different ways. We note that in some First Nation bands and communities, engagement and communication take place at different levels. In designing the OGS communication approach, we try to follow this engagement model:

- Chief-to-Chief: the most senior ministry person available should attend a meeting, visit a community, or initiate a relationship-building process.
- Technical-to-Technical: Because issues raised at meetings may be far ranging, participation by knowledgeable technical staff is important. For example, at our meetings, issues related to the *Mining Act*, rehabilitation or financial assurance, geology and mineral potential of the area, and historic exploration records have been raised. The presence of expert technical staff ensures the MNDM team can provide accurate and timely answers.
- Community-to-Community: The OGS uses mixed gender teams for our long-term First Nation relationship-building projects. Mixed gender teams more effectively communicate with a broad range of community members, including children, women, and elders. In our experience, the OGS welcome in, and insight gained about, a First Nation community is richer and more informed through mixed gender teams. OGS team members are knowledgeable about the OGS program and projects, but we try to include at least one team member who is responsible to interact with the community at a non-technical level. In addition, ongoing and routine communication between the community and the OGS commonly takes place through the non-technical team person, not the Senior Manager.

General Information Sharing

For some OGS activities, we communicate simply by correspondence to

- inform and describe in writing about the planned or anticipated OGS technical project or the pending release of an OGS map (Table 4.2)
- provide band with opportunity to identify its concerns

OGS considers the response for the First Nation community and determines if an accommodation should be provided. An accommodation may consist of a changed publication date, a deferred start to a project, or the temporary suspension of a project. While the OGS project is being executed, the OGS may directly or indirectly purchase goods and services from the community to support the mapping project.

Table 4.2. Information exchange between Ontario Geological Survey and a First Nation band.

Practice	Communication Steps	Communication Instruments
Inform First Nations by letter	By letter and fax, OGS program manager writes to inform Chiefs of First Nation communities about • Mapping projects planned for implementation in proximity to First Nation communities • OGS products that are planned for public release and that illustrate the geology in proximity to a First Nation community The information letter generally contains the following type of information and follows this approach • An introduction of the OGS manager, an explanation of the manager's role and responsibility, and an explanation of the responsibility of MNDM and OGS • If the technical project has already started, provide an explanation of the project, project location, project activities to date, project duration; project plans: be specific, but use technical language cautiously because the audience may not have a technical background • Identify required goods and services needed so that the Chief and Council can determine if the band is able to provide the services • After the letter is sent and faxed, the OGS program manager generally follows up with a telephone call to the Chief to confirm the letter was received and to discuss the content of the letter • Offer to have the project geologist or the manager visit the community during the field season to explain the OGS project • Provide the band an opportunity to determine if the OGS technical project raises concerns relating to treaty or aboriginal rights • Communicate regularly to provide project updates, changes, planned publication dates, and a description of publication plans There may be a need to address misperceptions (e.g., an OGS mapping project does not mean that a mine will be developed in that area).	• Letter and fax • Location map to illustrate the location of the mapping project • Copies of the published product may be provided if requested by the band or Tribal Council • Follow-up telephone conversations with the Band Office to ensure the fax has been received and determine when a teleconference can be set up with the Chief or designate to further discuss the intent of the letter

Face-to-Face Technical Information Exchange at Technical Meetings

- discuss band request to meet with Chief and Council to describe the technical project and discuss other items (Table 4.3)
- involve the Senior Manager and key technical staff
- offer to provide a presentation to the band and/or community to further increase awareness of the project
- usually involves several meetings throughout the duration of the OGS project
- provide an explanation and review of final project results after public release
- there should be constant information exchange regarding progress of technical OGS project, accommodations to address band treaty and aboriginal rights

Table 4.3. Face-to-face technical meeting between Ontario Geological Survey and a First Nation Band to discuss technical OGS project.

Practice	Communication Steps	Communication Instruments
Visit the community to meet with Chief and Council to explain the technical details of the OGS project	Usually follows initial communication by letter. The Chief or the OGS may request a face-to-face meeting to speak or discuss in greater detail the OGS technical project. Through dialogue with the Chief, the OGS program manager • confirms the meeting date, expectations of Chief and Council, items to be discussed, and participation by band • selects appropriate MNDM technical staff required to participate in the meeting to cover range of items to be discussed Two to three weeks in advance of the meeting, the OGS program manager confirms with the Chief by letter, fax, and through telephone conversation, the intent of the meeting, MNDM technical participants, and communication instruments. Initial meeting: discussions may focus on • high-level discussions about "who and what" MNDM and OGS are and the purpose of the OGS project • high-level discussions of who and what the First Nation is, what has happened historically and what are their concerns, and where the First Nation would like to see themselves in the future • the need and form of future meetings • in our experience, we are presented with a wide range of topics, many unrelated to the OGS program and mandate, at initial meetings OGS records its interpretation of meeting minutes. Generally, the band also records its set of minutes. Following the meeting, the OGS shares its copy of the minutes with the Chief to ensure the OGS understanding is accurate. During the life of an OGS technical project, several technical meetings may take place, including a meeting to present a copy of the final product to the community, coincident with, or following, the public release of the final geological product.	• Letters and faxes • Telephone conversations with Chief, Band Manager, Executive Assistant to Chief, or other key contact person identified by the Chief • Image-rich posters to illustrate the nature of the project and example project products • Examples of OGS geology maps, reports, and digital data products • Translate all materials where possible

Communication and Relationship-Building Steps

- Where there is a multi-year interest in an area, the OGS will work with willing communities to design a communication and relationship-building protocols (Table 4.4).
- Increasingly, the request to initiate communication and relationship building has come from a First Nation community.
- Each community is different; therefore, there is not a single operational approach that works for all communities. However, the common theme is that the process and approach must be developed jointly.
- To be successful, the process must meet the respective visions, comforts, goals, and practices of the community and the OGS; both have to be committed to the success of the project.
- The OGS mixed-gender team includes the Senior Manager and key non-technical staff because mixed-gender teams are received by, and communicate more effectively with, the community.
- This process ideally proceeds the planning and delivery of an OGS technical project, but may take place concurrently with the delivery of an OGS technical project.
- The goal is development of an open communication process and a trusting relationship.
- The process results in development of band-specific communication instruments, developed and used jointly to help inform the community and to receive community insight about their concerns, issues and advice.

The process must be delivered as a partnership with joint design, planning, decision making, delivery, support, monitoring and review, and reward.

Table 4.4. Relationship building between the Ontario Geological Survey and a First Nation band.

Practice	Communication Steps	Communication Instruments
Engage the band in a relationship-building process that may occur in parallel with technical meetings	Identify community Communities that practice traditional activities in an area, such as hunting, fishing, or gathering, expect to be contacted at an early point in the development of a project plan, ideally prior to the implementation of a technical project Face-to-face meetings generally follow initial communication by letter or a separate issue, such as a band-declared moratorium OGS implements relationship-building processes with bands located in areas where the OGS has a multi-year mapping interest. Relationship-building projects with several bands may occur concurrently, progress at different rates, following different steps Try to include the "right people", including the most senior program manager, the most knowledgeable technical person, and a non-technical person who is knowledgeable about the program, project or issue, but who is able to engage the community from a different perspective. A mixed gender team may be more effective	• illustrated "story-boards" (or posters) to visually explain the project and the roles of band and OGS prepared in English, local dialect (e.g., Ojibway) phonetics, and syllabics • glossary of administrative and technical words, in English, local dialect phonetics, and syllabics, to ensure a consistent and common understanding • documentation of meeting and events using photographs and notes • document that lists band issues and concerns

Table 4.4. continued

Practice	Communication Steps	Communication Instruments
Engage the band in a relationship-building process that may occur in parallel with technical meetings	Prior to the meeting, discuss with the Chief or designate, the best way to present material. Is it a band meeting where a formal presentation is required? Are hardcopy materials appropriate? Is a translator required and available? The initial meeting is usually "exploratory" or "discovery" in nature. The initial meeting may take 1 to 2 days. It may take several meetings for the band or OGS to articulate its issues and concerns, and to become sufficiently comfortable with the people at the table before a relationship-building project can be defined and formalized. The initial discussion may focus on issues and concerns articulated by the band or probing to explore the respective intents and form of the relationship-building process As the discussions mature, discussions focus on consideration and formal definition of • meaningful communication, shared values and principles that will guide the communication and relationship-building project • purpose, scope, and approach of the project • project management, operating, reporting, decision-making process, dispute resolution mechanisms, project action plan, deliverables, milestones, and duration • project costs and respective financial and in-kind contributions • respective roles, commitments and responsibilities • information flow to and from band and OGS • project monitoring, performance management, and measures of success • a more formal agreement, such as a Memorandum of Cooperation, as required	• take community members on local field trips or to a project site to see first hand how the activities are conducted • information sessions with band, clan and family meetings, local radio broadcasts, delivery of prospectors courses, information posters at local open houses and technical symposia • presentations to the school children focussing on "minerals in our lives", career opportunities and increased awareness of the earth around them through geology

MEASURES OF SUCCESS

The OGS monitors several measures of success over the long-term (Table 4.5). One possible outcome of the OGS communication and relationship-building practices is an increase in community knowledge about the OGS, its mandate, the minerals industry, and economic development choices available to the community. A second measure is a changed operational climate in proximity to the community.

Table 4.5. Performance indicators to measure the success of the Ontario Geological Survey communication and relationship-building processes.

Indicator	Measure
Improved communication	First Nation and OGS questions and concerns are communicated, discussed and addressed prior to becoming an issue
Increased MNDM–OGS awareness about the First Nation, their concerns, beliefs and economic development opportunities for the future	MNDM–OGS staff, managers and executives have a better understanding about the band decision-making processes for those communities where OGS has established a relationship
Increased First Nation awareness about MNDM and OGS	Chief, Council and band members have a better understanding about the mandate and role of MNDM and OGS
Increased First Nation awareness about the mineral industry	Chief, Council and Band members have a better understanding about the steps from exploration to mine development (e.g., mining sequence), and the rarity of a mineral concentration that can be mined
Strong relationship established between MNDM-OGS and First Nation bands	MNDM and OGS staff, managers and executives are able to exchange and test ideas and probe issues with First Nation contacts First Nation leadership is able to exchange and test ideas and probe issues with MNDM and OGS staff, managers and executives
Co-operation between MNDM–OGS and First Nation bands	Where appropriate, MNDM–OGS works in partnership with First Nation bands to define and maximize benefits for the band, mineral industry and OGS
Improved business climate in proximity to the community	Dialogue between First Nation bands and mineral industry with focus on building mutually beneficial business relationships

LESSONS LEARNED

The following lessons have been learned as a result of the communication and relationship-building practices:

- Responsibility and relationship-building: We have learned that for many communities, establishing a personal relationship is the prerequisite to developing a meaningful communication process or an operational relationship. We have learned that the relationship is developed between individuals, not with the organization.
- Many studies of relationship building between cultures identify the need to engage a community intellectually and emotionally, not just administratively, in order to build a strong personal relationship. This can involve a considerable investment of time for those involved in a relationship-building project.
- Communication is complex: Take time initially to determine respective expectations about what constitutes meaningful communication. Our views of what constitute "communication" may not be consistent with what the band considers to be "communication". Letters and faxes may not constitute meaningful communication.
- Constantly verify shared understanding: Continuously echo back with the Chief, Council and community to ensure there is a shared understanding about a word, phrase, decision, responsibility, or plan. Misunderstandings are common by all parties, although not intentional.
- Understand decision-making processes: Ensure that all understand the decision-making processes and who has decision-making authority.
- Information flow in a community: Take time to determine how information moves effectively to and from the community.
- Shared understanding of respective needs: take the time initially to ensure a plan is jointly developed and meets both the needs of the organization and those of the band. Misunderstandings often occur because neither party has effectively communicated what their respective needs are. Probe and ask questions to validate a shared understanding has been achieved.
- Committed staff: Those involved in the comprehensive relationship-building process must be committed to the goals of the project.
- Get to know the community: Staying in the community before, during and after meetings helps demonstrate a commitment to engage and learn about the band, its people, and the community perspectives. These informal occasions present an opportunity to engage a broad spectrum of band members to explain our role and to address questions. Community members have the opportunity to learn more about the OGS team, as individuals, in an informal setting. Also, we have discussed important issues and gained important insight outside the formal meeting room, in a more relaxed environment.

5. The Abitibi Greenstone Belt: A Program Update

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INTRODUCTION

The Precambrian Geoscience Section program in the Abitibi greenstone belt (ABG) is designed to facilitate exploration by providing current geological mapping in areas of high mineral potential at a variety of map scales. Parker (this volume) lists current core projects.

CURRENT PROJECTS

To date, the Abitibi compilation project has produced hard-copy and digital versions of the Timmins, Lake Abitibi, Kirkland Lake, Swayze and Matachewan map areas at a scale of 1:100 000 (Ayer and Trowell 1998; Ayer, Trowell and Berger 1999; Ayer and Trowell 2000; Ayer and Trowell 2002; Ayer, Trowell et al. 2003). A compilation sheet at a scale of 1:250 000 covering all of the above areas is planned for release in 2004. The compilation, in conjunction with new geochronological and lithogeochemical sampling, will enable further review and refinement of the assemblages and the timing of mineralization (Ayer, Amelin et al. 2002; Ayer, Ketchum and Trowell 2002; Ayer, Barr et al., this volume); establishment of a more formalized stratigraphy; and the erection of new metallogenic and geodynamic models for the evolution of the Abitibi greenstone belt. In addition, a number of ongoing mapping and research projects at a variety of scales (discussed below) are designed to focus on areas where we currently have an inadequate understanding of the relationships between mineralization and geology, and to provide new data for the compilation project.

The author is the representative for the Ontario Geological Survey (OGS) on the Technical Committee of the Discover Abitibi Initative (DAI). This is a community-based and directed program designed to stimulate exploration for, and eventual development of, mineral deposits within the AGB of northeastern Ontario. The program will be achieved through the co-operation and collaboration between Federal, Provincial and Municipal governments and private-sector partners. As well as a number of new geophysical surveys and other projects (www.discoverabitibi.com), DAI funding has resulted in initiation of a new mapping and metallogenic research project identified as the Greenstone Architecture Project (Ayer, Thurston et al., this volume). This project is focussed on an improved understanding of the controls on base metal and gold mineralization in a number of key areas with good economic potential in northeastern Ontario. The subprojects are described in detail in a separate Discover Abitibi section of this volume (*see* articles under the heading "Discover Abitibi Initiative").

Lindsay Hall and Michel Houle conducted 1:20 000 scale bedrock mapping for the Precambrian Geoscience Section in Shaw, Eldorado and Adams townships as part of an ongoing project to update geological mapping in the Timmins mining camp. This project follows bedrock mapping of Deloro Township in 2002 (Hall, MacDonald and Dinel 2003). The 4 major goals of this project are to 1) clarify lithologic uncertainties and to refine lithologic and assemblage boundaries; 2) to better understand the

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stratigraphic and structural nature of the Shaw Dome; 3) to evaluate the mineral potential of the area; and 4) to study the ultramafic metavolcanic and intrusive rocks. Goals 1 and 2 are addressed by Hall and Houlé (this volume). Goals 3 and 4 are addressed in more detail in an OGS–Discover Abitibi collaborative subproject by Houlé, Lesher and Hall (this volume). Numerous gold occurrences in the Shaw Dome demonstrate that gold mineralization is present south of the Porcupine–Destor deformation zone. However, relatively little gold exploration has been carried out in this part of the Timmins camp for the last 20 years. A close spatial relationship between extrusive and intrusive ultramafic rocks and sulphide-bearing iron formation occur extensively along the margins of the Shaw Dome. The combination of abundant olivine cumulate (i.e., high magma flux) and its proximity to sulphide-bearing iron formation (i.e., a sulphur source) results in favourable conditions for komatiite-associated nickel-copper-platinum group elements (PGE) deposits as is indicated by the presence of a number of past-producing nickel-copper mines in the map area.

Eby and Otto townships were mapped at 1:20 000 scale (Pigeon and Berger, this volume) during the 2003 field season as a part of a multi-year Precambrian Geoscience Section project covering parts of 7 townships west of Kirkland Lake (Berger 2001; Berger and Leblanc 2002). The close proximity of the map area to the Kirkland Lake gold camp emphasizes the need to advance our knowledge of the geology of the area. Like most gold occurrences in the Kirkland Lake area, gold deposits in Eby and Otto townships are spatially associated with the Larder–Cadillac deformation zone where gold mineralization occurs in quartz veins in proximity to northeast-striking faults, but also occurs south of the main deformation zone and appears to be focussed at the nose of tight regional-scale folds. The mafic to ultramafic rocks related to the Otto stock offer interesting prospects for nickel-copper and PGE mineralization.

A 1:50 000 scale reconnaissance mapping project to map 12 townships south of the Shining Tree area (Johns 2003) was initiated by Glen Johns this summer (Johns, this volume). The area has potential for volcanogenic massive sulphide (VMS) mineralization in Sheard, Amyot and Browning townships where sulphide mineralization is found mainly as massive and stringer pyrite in felsic metavolcanic rocks. In northern Dufferin Township, a graphitic and cherty argillite contains massive to disseminated pyrite, chalcopyrite and sphalerite in a 3 km long sulphide-bearing zone within mafic metavolcanic flows. A 2 to 3 m wide barite vein is currently being mined at Tracy Lake by Extender Minerals of Canada Limited. The age of the vein is Proterozoic and crosscuts Nipissing gabbro.

An increase in the number and significance of diamond discoveries in Archean rocks of the Michipicoten greenstone belt of the Wawa Subprovince in the last few years has resulted in rising interest in diamond exploration in the Wawa area. To date, all significant discoveries of diamonds in Archean rocks are located within Lalibert, Menzies, Leclaire and Musquash townships. 1:20 000 scale bedrock mapping was started this summer by Christine Vaillancourt in Menzies Township (Vaillancourt, Wilson and Dessureau, this volume). Menzies Township has never been part of any detailed mapping by the OGS. The heterolithic breccias and lamprophyric dikes that are hosts to the diamond occurrences are typically found in the northeast corner of the township above pillowed and massive mafic flows of the cycle 3 volcanic rocks.

Ayer, Conceição et al. (this volume) provide an update on the diamondiferous lamprophyres in the Michipicoten greenstone belt and the Abitibi greenstone belt in an effort to better understand their petrogenesis and to provide new exploration criteria. New results are reported on the ages and the lithogeochemical and isotopic composition of the dikes and compares the morphologies of diamonds from heterolithic breccias from the Wawa area with those in the Cobalt area.

CONCLUSIONS

In summary, many exciting new advances in our understanding of the geology of the Abitibi greenstone belt are being made. The reports in this volume demonstrate the merits of a diverse, but balanced, approach to geology in the Abitibi area using the traditional strengths of Precambrian Geoscience Section bedrock mapping, the comprehensive understanding of the ore deposits by the mining companies working in the area and the research skills of university geology departments. This balanced approach embraces projects at a wide variety of scales and methodologies that are required for the range of problems that exist. The projects range from belt-wide compilation, to township-scale bedrock mapping to extremely detailed outcrop-scale mapping. The program is also focussed on the economically important parts of the belt. We feel our integrated approach to applied research through collaboration with our mining company clients and the earth science departments of a number of universities is needed to advance our understanding of the geology and its relationship to mineral deposits in this geologically complex, but highly prospective, part of the province. We also feel confident that the maps, reports and theses resulting from this comprehensive program will provide many new ideas and concepts that are, and that will continue to be, directly applicable to exploration for new mineral deposits.

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6. Project Unit 00-011. Geology and Mineral Potential of Shaw, Eldorado and Adams Townships, Shaw Dome Area

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INTRODUCTION

The Precambrian Geoscience Section, Ontario Geological Survey (OGS) conducted bedrock mapping, at a scale of 1:20 000, in Shaw, Eldorado and Adams townships as part of an on-going project to update geological mapping in the Timmins mining camp. This project follows bedrock mapping of Deloro Township in 2002 (Hall, MacDonald and Dinel 2003). The Shaw Dome (Pyke 1974) is located within the map area, south of Timmins, and is a geologically enigmatic feature.

The goals of this project are four-fold: 1) to clarify some lithologic uncertainties and to refine lithologic and assemblage boundaries; 2) to better understand the stratigraphic and structural nature of the Shaw Dome; 3) to evaluate the mineral potential of the area; and 4) to study the ultramafic metavolcanic and intrusive rocks. Goals 3 and 4 will be addressed in more detail in a OGS–Discover Abitibi subproject described by Houlé, Lesher and Hall (this volume). Geophysical and diamond-drill hole data are being used to aid in the extrapolation of geological contacts across the many large areas obscured by overburden.

REGIONAL SETTING

The Abitibi Subprovince of the Superior Province consists of a stratigraphically continuous succession of Archean metavolcanic and metasedimentary rocks that developed in an ensimatic basin (Ayer et al. 2002). These rocks have been subdivided into 9 temporally constrained stratigraphic assemblages (Ayer et al. 1999a, 1999b).

Of specific relevance to this project, the Shaw Dome area (Pyke 1974) is outlined by an outward-facing stratigraphic contact between the upper Deloro and lower Tisdale assemblages (Pyke 1982). The core of the dome is a sequence of mafic to felsic calc-alkalic metavolcanic rocks capped by iron formation that is interpreted to be part of the Deloro assemblage (2730 to 2725 Ma: Ayer et al. 1999b). The iron formation is unconformably overlain by komatiitic and subsequent tholeiitic mafic to felsic metavolcanic rocks of the lower Tisdale assemblage (2710 to 2703 Ma: Ayer et al. 1999b). Intrusions of ultramafic, mafic and felsic affinities intrude all supracrustal rocks in the Shaw Dome.

GEOLOGY OF SHAW, ELDORADO AND ADAMS TOWNSHIPS

The map area is underlain by calc-alkalic and tholeiitic metavolcanic rocks and ultramafic, mafic and felsic intrusions. An attempt has been made to distinguish the supracrustal rocks based solely on field

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observations and stratigraphic relationships (Figure 6.1). Three packages of metavolcanic and metasedimentary rocks have been identified "Supracrustal Package A", "Supracrustal Package B" and "Supracrustal Package C". This will be subject to modification when lithogeochemical, geochronological and petrographic results have been assessed. Pyke (1982) included rocks herein designated as Supracrustal Packages A and B as the upper Deloro Group and those designated as Supracrustal Package C as the lower Tisdale Group.

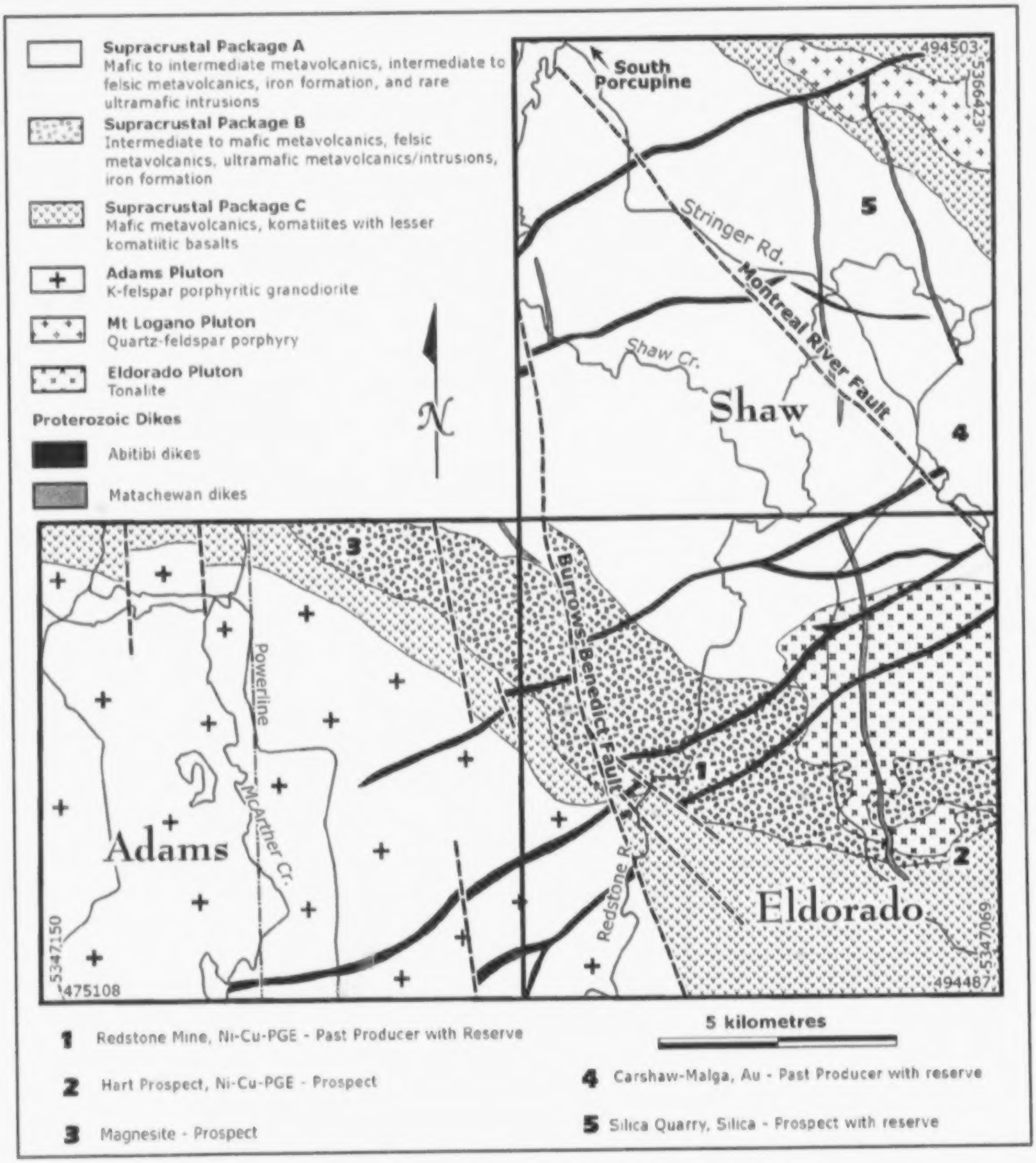
Supracrustal Package A
Mafic to intermediate metavolcanics, intermediate to felsic metavolcanics, iron formation, and rare ultramafic intrusions
Supracrustal Package B
Intermediate to mafic metavolcanics, felsic metavolcanics, ultramafic metavolcanics/intrusions, iron formation
Supracrustal Package C
Mafic metavolcanics, komatiites with lesser komatiitic basalts
Adams Pluton
K-felspar porphyritic granodiorite
Mt Logano Pluton
Quartz-feldspar porphyry
Eldorado Pluton
Tonalite
Proterozoic Dikes
Abitibi dikes
Matachewan dikes
N
South Porcupine
494503
5366423
Stringer Rd.
Montreal River Fault
Shaw Cr.
Shaw
5
4
3
Burrows Benedict Fault
Powerline
McArther Cr.
Adams
Redstone R.
Eldorado
1
2
5347150
475108
5347069
494487
5 kilometres
1 Redstone Mine, Ni-Cu-PGE - Past Producer with Reserve
2 Hart Prospect, Ni-Cu-PGE - Prospect
3 Magnesite - Prospect
4 Carshaw-Malga, Au - Past Producer with reserve
5 Silica Quarry, Silica - Prospect with reserve

Figure 6.1. Simplified geology of Shaw, Adams and Eldorado townships in the Shaw Dome area.

Supracrustal Package A

Supracrustal Package A comprises dominantly mafic to intermediate metavolcanic rocks with lesser intermediate to felsic metavolcanic rocks and chert-rich iron formation horizons. All of these rocks display a weak to moderate tectonic fabric and are metamorphosed to lower greenschist facies.

MAFIC TO INTERMEDIATE METAVOLCANIC ROCKS

Calc-alkalic (Pyke 1982), mafic to intermediate metavolcanic rocks of Supracrustal Package A typically display a pale buff-green, rarely bluish-green weathering surface and a medium to dark grey-green, rarely dark blue-green fresh surface. They display well-preserved primary structures including pillows, pillow breccia, hyaloclastite, massive flow and lapilli to block tuffs.

Massive flows have an apparent thickness of up to 80 m (with a true thickness of approximately 40 m considering the approximate dip of bedding of 30°). Pillows display a range of sizes (0.3 by 0.7 m up to 1.5 by 4 m) and a range of shapes (regular cuspate pillows with aspect ratios of 1:3 to 1:4; amoeboid pillows; elongate "mattress"-shaped pillows with aspect ratios of up to 1:20). Pillow selvages are typically dark and more penetratively foliated. They range from 2 cm thick on small pillows to 10 to 15 cm thick in the larger and amoeboid pillows. Pillow selvages are commonly thick where hyaloclastite is present. Chert fragments may be present in the interstitial pillow areas and in pillow breccia proximal to iron formation horizons. Massive and pillowed flows commonly display cooling fractures as pale, 2 to 4 mm wide, commonly positive weathering, wavy lines on the weathered surface, spaced from 1 to 10 cm apart. Spacing of these fractures is reduced with proximity to flow contacts.

The mafic to intermediate volcaniclastic rocks display a range of characteristics. Typically, the matrix and fragment compositions are somewhat different accentuated by differences in colour and weathering patterns. Fragments that are more siliceous than the matrix have a pale weathered surface and stand out in positive relief on the outcrop surface in comparison with the matrix (Photo 6.1a). The fragments in these exposures range in size (lapilli to blocks), abundance (fragment to matrix supported) and composition (including chert and more mafic to intermediate fragments, displaying a range of textural characteristics).

Less extensively exposed tuffs display a matrix that is more siliceous than the predominant fragment type. In these exposures, the matrix is pale and stands out in positive relief relative to the fragments.

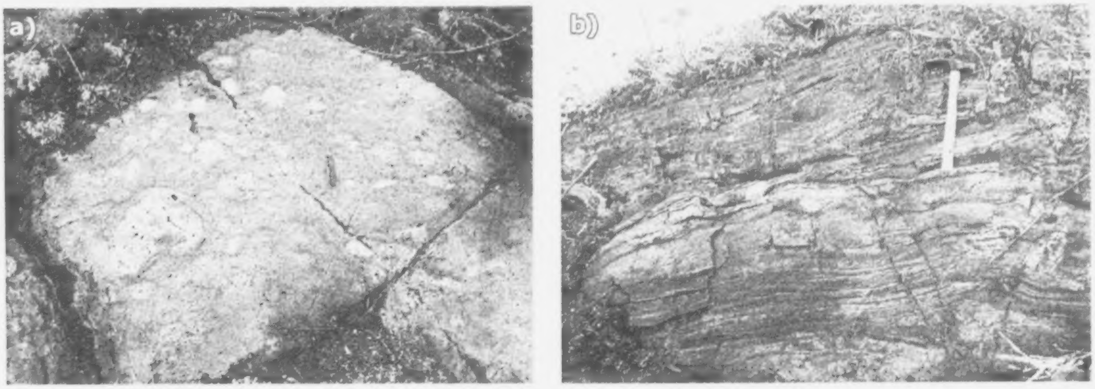

Photo 6.1. Examples of the rock types of Supracrustal Package A: a) Mafic to intermediate tuff breccia. b) Banded iron formation (oxide bearing).

Fragments are relatively well sorted, angular and lapilli sized with only rare compositional variations. Although the tuffaceous mafic to intermediate metavolcanic rocks commonly display distinctive stratigraphic variations on the outcrop, these horizons are not traceable between outcrops due to the abrupt lateral facies variation that is inherent to this type of volcanic deposit.

Supracrustal Package A mafic to intermediate metavolcanic flows are commonly porphyritic with either feldspar and/or altered mafic phenocrysts and phenoclasts. Those rocks that are not porphyritic are either aphyric or possess a fine- to medium-grained gabbroic texture. The latter is most commonly found in the more mafic end-members displaying either massive flow or large pillow structures. Amygdules are present in most mafic to intermediate metavolcanic rocks in varying abundances and sizes. Carbonate (typically calcite), quartz, and quartz-rimmed carbonate fillings are most common, while chlorite-quartz ± carbonate fillings are locally present. A vesicular appearance on the weathered outcrop surface occurs where the carbonate fillings have been weathered out and dissolved.

Stratigraphic tops were established using a variety of indicators. These include pillow shape, vesicle or amygdule density, cooling fracture density, relative position of hyaloclastite and overall grading in the fragmental units.

INTERMEDIATE TO FELSIC METAVOLCANIC ROCKS

Intermediate to felsic, calc-alkalic (Pyke 1982) metavolcanic rocks of the Supracrustal Package A are stratigraphically interleaved with the more mafic metavolcanic rocks. The intermediate to felsic metavolcanic rocks are very similar in outcrop character to their more mafic counterparts. Contacts are gradational and distinguishing the units is very subjective. The field criteria used were colour (pale chalky buff on weathered surfaces; pale to medium green-grey or yellow-grey or dark grey on fresh surfaces), relative hardness, and the presence of sericite and relatively low abundance of chlorite.

Intermediate to felsic metavolcanic horizons also display a variety of primary characteristics including lapilli and block deposits, massive flows and rare pillowed flows. Both porphyritic and aphyric textures were noted. Phenocryst compositions include feldspar, chlorite after amphibole, feldspar and chlorite and, rarely, feldspar and quartz. Both feldspar and chlorite phenocryst abundance ranges up to 15% and up to 4 mm in size. Amygdules are locally very abundant in the more intermediate rocks of this unit. These are typically quartz-rimmed carbonate amygdules that range up to 35 mm along their long axis. Slightly positive weathering, pale, closely spaced (0.5 to 1.5 cm), thin (0.2 to 0.4 cm), curviplanar features are interpreted to represent flow-banding in several exposures in east-central Shaw Township.

CHERT-RICH IRON FORMATION

Chert-rich banded iron formation is exposed near the stratigraphic top of Supracrustal Package A. In general, the iron formation can be classified using the iron-bearing minerals present in the rock. Oxide-bearing (magnetite ± hematite), sulphide-bearing (pyrite, pyrrhotite ± chalcopyrite) and chert-dominated (with a relative paucity of iron-bearing minerals) iron formation types are present. The oxide-bearing iron formation commonly consists of thin layers of dark grey to black, very fine-grained magnetite (Photo 6.1b). The sulphide-bearing iron formation contains large, typically euhedral pyrite that locally appears to be associated with the presence of quartz and quartz-carbonate veins. This has been interpreted to indicate that the sulphide minerals formed as a result of sulphidization and replacement of primary magnetite. Quartz veins, locally more than 2 m wide, are common throughout the iron formation.

Two thick, largely parallel horizons of chert-rich iron formation occur along the northeast flank of the Shaw Dome:

1. Lower horizon: The stratigraphically lower horizon of chert-dominated banded iron formation is typically 30 m wide, but locally thickens up to 80 m across strike (possibly as a result of structural repetition). This horizon outcrops in prominent, "whale-back" exposures that are elongate and parallel to the stratigraphy. The horizon is northwest-striking across the northeast corner of Shaw Township. Where exposed to the west and south of Goose Lake, in northern Shaw Township, this horizon is oxide bearing. However, further to the southeast, this unit is locally oxide bearing, oxide and sulphide bearing and chert dominated. The chert beds range from 2 cm to massive beds of pure chert that are over 1 m in thickness, generally thickening towards the stratigraphic top of the package. The chert is grey or pale pink and aphanitic where the formation is well banded, but becomes white and sugary in texture in the more massive horizons. Magnetite bands are relatively abundant (up to 50% of the strata over short intervals) and thick (up to 2 cm) in the stratigraphically lower well-banded sections, especially in the northwest exposures. However, the magnetite bands are thin (0.2 to 0.8 cm) and scarce in the upper, more massive sections.
2. Upper horizon: A thick (30 to 40 m) unit of chert and sulphide-bearing iron formation is located at the stratigraphic top of Supracrustal Package A. The upper horizon is exposed only 200 to 250 m to the northeast of the lower horizon described above in northern Shaw Township. Where exposed in central and southeast Shaw Township, these intermittent exposures of the upper horizon consist dominantly of chert, with localized and varied sulphidization. Banding is best developed near the bottom of the iron formation. Rare, thin argillite beds are present between the chert beds in some exposures. Interlayered black and white chert (2 to 4 cm wide layers) is present locally within the middle to middle upper sections of the iron formation.

Other smaller, discontinuous chert-dominated and oxide-bearing iron formation horizons occur throughout much of the volcanic stratigraphy of Supracrustal Package A, most notably in Shaw Township. A distinctive horizon of dismembered chert hosted in a matrix of mafic to intermediate volcanic rock is traceable on both sides of the Burrows–Benedict fault in northern Deloro and Shaw townships. This unit provides a useful marker horizon to delineate the displacement on the fault. The iron formation horizons, though laterally varied and locally discontinuous, should provide stratigraphic markers to aid in the construction of geological maps and in the interpretation of both the stratigraphy and the structural complexities of the Shaw Dome.

Supracrustal Package B

Supracrustal Package B is found only along the south flank of the Shaw Dome in Adams and Eldorado townships. It consists of intermediate to mafic metavolcanic rocks, ultramafic metavolcanic and intrusive rocks and felsic metavolcanic rocks with lesser iron formation. All of these rocks display a moderate to strong tectonic fabric and are metamorphosed to lower greenschist facies. With the exception of the ultramafic rocks, these rocks display significantly more strain than the rocks of Supracrustal Package A.

INTERMEDIATE TO MAFIC METAVOLCANIC ROCKS

Calc-alkalic (Pyke 1982), intermediate to mafic metavolcanic rocks of Supracrustal Package B are typically medium buff-beige on the weathered surface and medium to dark grey on the fresh surface. Flattened to highly flattened fragmental, massive and possibly pillowed metavolcanic rocks are present.

Fragment size varies from ash to blocks. Quartz, carbonate and quartz-carbonate amygdules are present in the metavolcanic flows. Unusual, highly magnetic, magnetite-bearing tuff breccia to pyroclastic breccia and pillowed flows are locally present (Photo 6.2a). The magnetite is irregularly distributed within the fragmental unit and is in higher abundance in the selvages of the pillowed flows. Locally, thin layers of massive magnetite occur between the fragments in the tuffaceous rocks.

FELSIC METAVOLCANIC ROCKS

Few exposures of calc-alkalic (Pyke 1982) felsic metavolcanic rocks occur in central and east-central Eldorado Township within Supracrustal Package B. These siliceous rocks are medium to pale buff-beige and chalky with pale yellow-green patches on the weathered surface. Fresh surfaces are white to medium grey. Lapilli-tuff, volcanic *in-situ* breccia, and massive flows are present. These rocks are penetratively foliated throughout the area.

ULTRAMAFIC METAVOLCANIC ROCKS AND INTRUSIONS

The ultramafic rocks of Supracrustal Package B consist of intimately associated flows and high-level intrusive components. Determination of the intrusive versus extrusive origin of these rocks is one of the goals of the subproject detailed in Houlé, Lesher and Hall (this volume). The ultramafic rocks are pale orange-brown or, rarely, bone-white weathering with dark green, rarely pale green fresh surfaces. Serpentinization is pervasive. Primary mineralogy can be estimated as the serpentine is pseudomorphic after the primary igneous minerals. Most ultramafic exposures consist of dunite (Photo 6.2b) to peridotite. Pyroxenite and rocks of gabbroic composition are locally present in association with the other ultramafic components of this package.

Well-preserved primary structures include massive cumulate (Photo 6.2b) and non-cumulate textures, with lesser spinifex textures, spinifex fragments and polyhedral jointing. Flow contacts are recessively weathered and commonly display a weak foliation not present in the rest of the outcrop. Serpentine veins crosscut the flows and intrusions. The ultramafic rocks exposed in northeast Adams Township are overprinted by a strong carbonate alteration with abundant magnesite and iron carbonate minerals present. This alteration locally obscures the primary features.

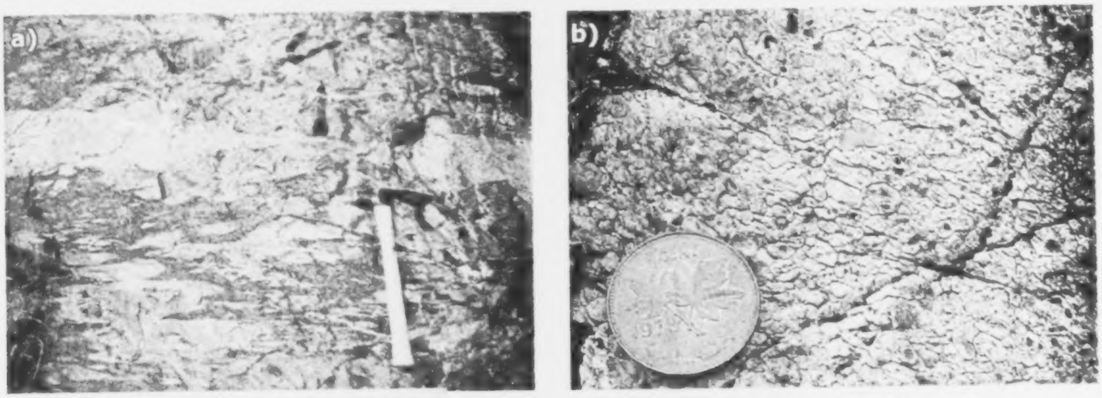

Photo 6.2. Examples of rocks of Supracrustal Package B. a) Intermediate to mafic tuff breccia to pyroclastic breccia intruded by a felsic dike. Volcanic matrix partially replaced by magnetite. b) Fine-grained olivine adcumulate.

IRON FORMATION

Iron formation horizons occur at different stratigraphic levels in Supracrustal Package B. The iron formation in this package can be classified into four categories: 1) banded iron formation (oxide bearing); 2) siliceous banded iron formation (chert dominant); 3) banded iron formation (sulphide bearing); and 4) massive iron formation. Categories 1, 2 and 3 bear a strong resemblance to those described within Supracrustal Package A. None of these iron formation horizons, however, are as thick or as laterally traceable as those observed in Supracrustal Package A. The massive iron formation is a 1 to 5 m horizon of massive, fine-grained magnetite with accessory pyrrhotite and pyrite. This rock type was not observed in Supracrustal Package A.

Supracrustal Package C

Exposure of Supracrustal Package C is relatively limited in the map area and was mapped in two sequences on the southwest and the northeast flanks of the Shaw Dome. The sequence on the southwest flank of the dome strikes northwest from southeast Eldorado Township to northwest Adams Township. This sequence consists primarily of mafic metavolcanic rocks with lesser ultramafic metavolcanic rocks. The rocks exposed along the northeast flank of the dome (northeastern Shaw Township) are ultramafic metavolcanic rocks. All of these rocks display a weak tectonic fabric and are metamorphosed to lower greenschist facies. A wide high-strain zone transects the rocks of Supracrustal Package C in west Eldorado Township, resulting in a strong tectonic and metamorphic overprint on these rocks. Thin felsic dikes intrude all units of this package.

MAFIC METAVOLCANIC ROCKS

Exposed only along the southwest flank of the Shaw Dome, the mafic metavolcanic rocks of Supracrustal Package C have tholeiitic affinities (Pyke 1982) and display a medium to pale green weathered surface with medium green fresh surfaces. Pillowed and massive flows are the two main volcanic facies in this package of rocks with pillowed flows being dominant. Pillows display a range of sizes (0.15 by 0.25 m, up to 0.5 by 1.5 m) and shapes (regular cuspate pillows (Photo 6.3a) with aspect ratios of 1:2; mushroom-shaped to amoeboidal pillows with aspect ratio of 1:4). The selvages are composed of interpillow breccia with mafic metavolcanic fragments or fine-grained hyaloclastite. Some cooling fractures were observed, but

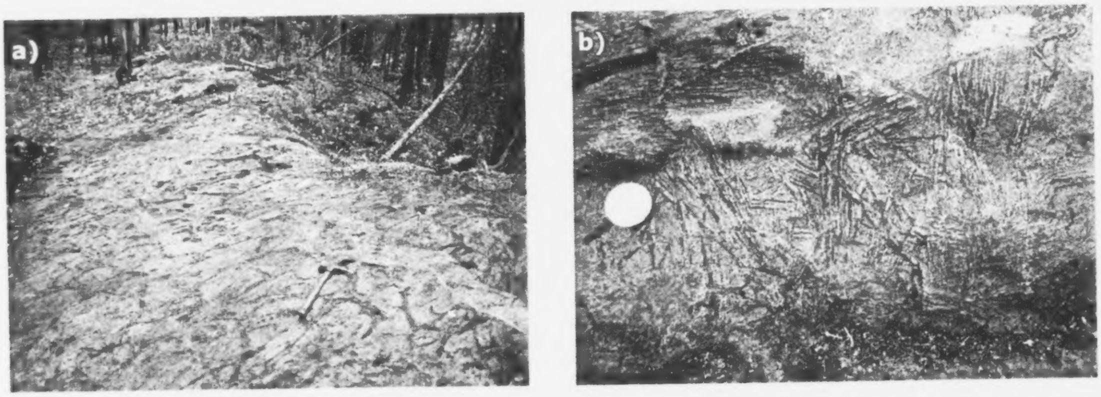

Photo 6.3. Examples of rocks of Supracrustal Package C. a) Mafic pillowed flows intruded by a felsic dike. b) Randomly oriented olivine spinifex in komatiite.

are less common than in the volcanic flows in Supracrustal Package A. Massive flows are devoid of primary structures, however, they locally display a fracture network similar to the polyhedral jointing typically found in komatiites and komatiitic basalts.

Mafic metavolcanic rocks of Supracrustal Package C are commonly aphyric. Gabbroic textures occur in large pillow structures. Vesicles are present in varying abundances and sizes, but are generally of a smaller size and lower abundance than in the mafic metavolcanic rocks of Supracrustal Package A.

The mafic metavolcanic rocks that occur in the high-strain zone in western Eldorado Township are distinct in character. These rocks are mylonitized and amphibolitized with dark and pale green "streaks" due to the relative abundance of hornblende and epidote. These rocks are interpreted to be pillowed and massive mafic metavolcanic rocks that are intimately associated with gabbro-amphibolite and highly strained felsic intrusive rocks.

ULTRAMAFIC METAVOLCANIC ROCKS

The komatiitic ultramafic metavolcanic rocks of Supracrustal Package C are pale orange-brown, rarely, bone-white weathering and dark green, rarely pale green on the fresh surface. They display well-preserved primary structures including massive (cumulate and non-cumulate), spinifex textures, spinifex-breccia, spinifex fragments, polyhedral jointing and flow-breccia. Serpentinization is pervasive and serpentine veins crosscut the flows.

Several, 0.5 to 30 m thick flows have been delineated within the ultramafic metavolcanic rocks and consist of massive and internally layered flows. The massive flows are olivine meso- to orthocumulates with polyhedral jointing locally developed at the top of the flow. Layered flows include a lower olivine orthocumulate zone and an upper spinifex zone (Photo 6.3b). The upper contacts of the layered flows commonly display polyhedral jointing.

Archean Mafic Intrusions

Supracrustal rocks of all packages are intruded by mafic intrusions. These rocks are typically fine- to medium-grained gabbros consisting of plagioclase, amphibole and chlorite. Limited fabric development, a characteristic diamond-shaped joint pattern, and an absence of volcanic structures and textures distinguish these rocks from the fine-grained metavolcanic rocks they intrude. A large body in central Shaw Township displays pegmatitic patches near the centre of the intrusion. The mafic intrusive rocks exposed in the high-strain zone in western Eldorado Township are medium-grained, black, massive amphibolite.

Archean Felsic Intrusions

ADAMS PLUTON

Occupying much of Adams Township, the Adams pluton extends into Price, Ogden, Deloro, McArthur, Eldorado and Douglas townships. The pluton is typically granodioritic in composition and contains accessory minerals that include abundant hornblende, epidote, limited intergrowths of biotite with hornblende and local euhedral, orange titanite. Coarse-grained, equigranular and potassium feldspar megacrystic textures are present within this pluton. The potassium feldspar megacrysts appear to have zones of inclusions consisting of albite and quartz. This can be interpreted to reflect a late growth of the feldspar crystals, over-growing already crystallized quartz and albite (G.P. Beakhouse, OGS, personal communication, 2003). Small dioritic inclusions are relatively abundant and distributed throughout the pluton. These are interpreted to represent a minor, coeval, intermediate phase of this pluton (G.P. Beakhouse, OGS, personal communication, 2003). Pegmatitic, amphibolitic enclaves are present within the granodiorite in one locality.

GRANODIORITE TO TONALITE INTRUSIONS

Other felsic to intermediate intrusive bodies are exposed in the map area. The largest of these is a tonalitic intrusion that underlies approximately 15 km^2 of east-central Eldorado and west-central Langmuir townships. This intrusion is a medium- to fine-grained, biotite-hornblende-epidote tonalite with minor quartz diorite. Numerous dikes and small bodies intrude the supracrustal rocks that are exposed between the Adams pluton in the west and the large tonalite intrusion in the east. These small intrusive bodies and dikes display a range of compositions, including granodioritic, dioritic and tonalitic. They are locally aplitic, porphyritic, and fine to medium grained with a phaneritic texture. No specific associations with the larger neighbouring plutons have yet to be assigned to these diverse dikes.

MT. LOGANO PORPHYRY

Exposed in the northeast corner of Shaw Township, the Mt. Logano porphyry is the largest of the high-level porphyry intrusions in the Timmins camp. Abundantly quartz and albite porphyritic, this body is variably strained and altered. Accessory minerals include pyrite, actinolite, apatite and very fine chlorite. In general, it is least deformed at the core of the intrusion and shows progressively more strain toward its margins, where it is fissile and penetratively sericitized. Small fuchsitic xenoliths were observed.

Potassic Dikes

An unusual intrusive unit is exposed within the tonalitic intrusion in Eldorado Township. This rock is fine grained with very fine olivine and pyroxene phenocrysts (Pyke 1975) and locally contains abundant fragments of tonalite, granodiorite and diabase. This pink-brown weathering, dark green fresh rock is interpreted to be lamprophyric in composition (Pyke 1975).

Small, straight dikes were observed to intrude fragmental metavolcanic and felsic to intermediate intrusive rocks in central Eldorado Township. The dikes are of relatively limited extent and are 10 cm to greater than 10 m wide. These grey to brown, slightly recessive weathering rocks are streaked dark green to black and pink on the fresh surface. They are tentatively correlated with the above described lamprophyre.

Proterozoic Dikes

MATACHEWAN SWARM

Weakly magnetic mafic dikes of the Paleoproterozoic Matachewan dike swarm intrude all of the above rock units. Exposures of Matachewan dikes are distinctive orange-brown, positive weathering, and commonly elongate parallel to the dike trend. These dominantly north-northwest-trending dikes are largely undeformed, unmetamorphosed and unaltered, with the exception of some epidote mineral growth observed on subhorizontal joint surfaces. A rare feature of these mafic intrusive rocks is the presence of green, plagioclase phenocrysts or glomerocrysts that range up to 8 cm across. The intrusions commonly follow pre-existing structures and zones of weakness, but are observed to bifurcate. Local small swarms of aphanitic to porphyritic dikelets extend laterally from the main body of a dike taking advantage of the main fabric in the country rock. In the map area, Matachewan dikes have been observed to be up to 40 m wide. These dikes are easily delineated between exposures using airborne geophysical data due to their distinctive magnetic signature and straight trends.

ABITIBI SWARM

West- to west-southwest-trending, Mesoproterozoic, Abitibi dikes crop out in the map area in several localities. These ophitic textured, olivine gabbro dikes weather readily, resulting in the presence of coarse orange sand around exposures. Abitibi dikes are typically 20 to 50 m wide. Some exposures of massive, black, featureless gabbro, commonly with accessory quartz, occur along strike with exposures of more "typical" Abitibi gabbro. Similar to the Matachewan swarm, Abitibi dikes are weakly magnetic yielding distinctive geophysical trends. The Abitibi dikes are the youngest rocks in the map area since they intrude Matachewan dikes.

STRUCTURE

The character of the deformation preserved in the rocks of the map area is spatially variable. In Shaw Township, the rocks generally display limited deformation. The supracrustal rocks are nearly flat lying, dipping shallowly to the northeast in the north and swinging gradually to an easterly dip in the south part of the township. High-strain zones are discrete and generally trend north-northwest and west-northwest. In Eldorado Township, the stratigraphy is steep to upright and commonly east striking. The area is complicated by folds and faults and, in general, the rocks display the effects of significantly more strain than the rocks exposed in Shaw Township. Adams Township is occupied in large part by the strain resistant Adams pluton. During episodes of deformation that postdate the emplacement of the pluton, this body behaved as a buttress about which stresses were deflected into the surrounding supracrustal rocks. The rocks adjacent to the pluton in northeast Adams and south Eldorado townships, therefore, display somewhat complex deformation.

Some general observations are possible. The impacts of two fabric-forming, deformational episodes have been recognized throughout the map area. S_1, the earliest deformational fabric, is most pervasively developed in the metavolcanic rocks of Supracrustal Package A. Tight to isoclinal, asymmetric folds identified in iron formation at the outcrop scale are tentatively interpreted to be associated with this early fabric. This would imply that D_1 (the earliest deformational event to affect these rocks) is recorded in the rocks as F_1 folds and a S_1 foliation that is axial planar to the F_1 folds. S_1 is an anastamosing, weak to strong, penetrative, mineral foliation. This feature is commonly transposed into the S_2 fabric and is, therefore, locally difficult to distinguish from S_2. D_2 features include a straight, weak to strong, moderately penetrative foliation (S_2). S_2 is typically more obvious on the weathered surface of an outcrop, whereas S_1 is the more penetrative foliation. On outcrops where D_2 has effectively transposed D_1, a composite main foliation was measured. This main foliation is generally west to southwest striking.

In northern Shaw Township, a set of crenulations (F_3) can be observed where S_1/S_2 surfaces are pronounced, especially in highly sericitized and chloritized rocks. The hinges of these crenulations are near horizontal. Similarly, conjugate kinks (F_4) folds are locally developed with steeply dipping hinges and near-vertical axial planes. Both F_3 and F_4 folds are interpreted to be associated with movement on the Porcupine–Destor deformation zone as these folds become progressively less abundant to the south.

In general, the rocks of Supracrustal Package B preserve more evidence of strain than those of Supracrustal Packages A and C. Moderate to strong fabric development, flattened volcanic fragments and fold interference patterns are common features in Supracrustal Package B.

A west-northwest-striking zone of high strain cuts the rocks of Supracrustal Package C and, to a lesser extent, the rocks of Supracrustal Package B in western Eldorado Township. This zone of intense fabric development and mylonitization is associated with the Burrows–Benedict fault (*see* Figure 6.1). Regional horizontal offset on this fault is 2 to 3 km (Ayer and Trowell 1998) in a sinistral sense. This is consistent with kinematic indicators observed in this area of high strain.

The nature of the Shaw Dome is somewhat enigmatic in that it has yet to be established how this "domal structure" arose. Pyke (1982) put forth two hypotheses: 1) a structural dome resulting from superimposed folds correlative with those mapped to the north of the Porcupine–Destor fault; and 2) domal uplift of flat-lying strata as the result of the diapiric emplacement of a large granitoid stock under the strata. Both of these hypotheses require the subsequent erosion of the uplifted strata to expose the older rocks in the core of the dome.

In order to form an ovoid structural dome through superimposed folding, the axial planes of the two folds must be near vertical and mutually perpendicular. Such fold interference would also result in the Shaw Dome being flanked by basinal structures and other, more distal domes in the classic "egg carton" geometry. This is not the case. The axial planes of the large-scale folds north of the Porcupine–Destor deformation zone (i.e., the Porcupine Syncline and the Kayorum Syncline–Tisdale Anticline fold pair) are oblique rather than perpendicular and do not give rise to structural domes.

The absence of an exposed granitoid intrusion in the core of the Shaw Dome might throw some doubt on the second hypothesis. However, the presence of a low Bouguer gravity anomaly in the centre of the Shaw Dome can readily be interpreted as resulting from the presence of a large granitoid pluton lying below a relatively thin veneer of denser supracrustal rocks. The small porphyritic, equant and aplitic felsic to intermediate intrusions through the core of the Shaw Dome could be associated with a large, unexposed granitoid pluton that underlies it. The apparent absence of a metamorphic aureole in the supracrustal rocks at the core of the dome would suggest that an underlying pluton is too deep to have had a thermal impact on the overlying rocks.

Outcrop-scale folds in the iron formation and komatiitic rocks of Supracrustal Packages A and B do not fit geometrically with either of Pyke's hypotheses regarding the generation of the Shaw Dome structure. It is herein suggested that folding of these units existed prior to the uplift associated with emplacement of an underlying pluton.

MINERALIZATION

Numerous types of mineral occurrences are present in Shaw, Eldorado and Adams townships including gold, nickel, copper, silica, magnesite and platinum group elements (Table 6.1). Other commodities, such as silver, iron, zinc and asbestos, have drawn the attention of mineral explorationists to the Shaw Dome over the past 80 years.

Table 6.1. Summary of mineral properties in the mapping area and their main commodities (compiled by the Timmins Resident Geologist Office in South Porcupine from assessment files).

	Shaw Township	Adams Township	Eldorado Township
Past Producer with Reserve	2	0	1
Prospect with Reserve	1	0	1
Prospect	1	0	0
Occurrence	11	3	10
Discretionary Occurrence	4	3	5
Main Mineralization	Au, Si	mgs, Ni-Cu, Au	Ni-Cu, PGE

Abbreviations: Au, gold; Si, silica; mgs, magnesite; Ni-Cu, nickel-copper; PGE, platinum group elements

Gold

Gold properties in the map area have been sporadically investigated for several decades. Gold mineralization is associated with a diversity of rock types, assemblages, structures and alteration characteristics in the map area. The following points illustrate the diversity of geological characteristics displayed by the gold occurrences:

- host rocks include iron formation; mafic, felsic and ultramafic metavolcanic rocks; and felsic-intermediate and ultramafic intrusive rocks;
- wall-rock alteration consists of ubiquitous carbonatization and variable chloritization, silicification and serpentinization;
- gold is variously associated with other precious and base metals, including silver, copper, nickel and the platinum group elements, and with sulphide minerals, such as pyrite, pyrrhotite and arsenopyrite;
- gold is localized within fold closures and small, late brittle to brittle-ductile faults;
- gold occurs with disseminated and stringer sulphide mineralization and quartz-carbonate or quartz-chlorite veins that may or may not be deformed.

Typically, however, the host rock lithology determines the type of alteration and mineral associations present with the gold. The veins, folds and faults serve to focus and concentrate the deposition (or redeposition) of the gold in the host lithology. The only characteristic common to all gold deposits in the area is the presence of quartz and/or quartz-carbonate veins.

Nickel-Copper–Platinum Group Element Mineralization

Several nickel-copper (Ni-Cu)–platinum group element (PGE) mineral occurrences are known in the map area including the Redstone Mine and Hart prospect. This mineralization is mainly associated with extrusive and/or intrusive ultramafic rocks. Komatiite-hosted deposits contain a variety of mineralization types (Lesher and Keays 2002; *see also* Houlé, Lesher and Hall, this volume). The most prospective Ni-Cu-(PGE) mineralization type in the Shaw Dome area is the stratiform basal and/or footwall consisting of massive to disseminated sulphide mineralization occurring at or near the base of the peridotitic or dunitic komatiite units. Sulphide minerals at these occurrences include pyrrhotite, pentlandite, chalcopyrite, pyrite ± millerite, gersdorffite and violarite. A close spatial relationship between sulphide-bearing iron formation and ultramafic rocks is present at all significant Ni-Cu-(PGE) mineral occurrences in the Shaw Dome area.

Magnesite-Talc

Several occurrences of magnesite are found in the Shaw Dome area including the Canadian Magnesite deposit (south-central Deloro Township; owned by Globex Exploration Minerals); the Allerston deposit (southwestern Whitney Township); and another Globex Exploration property in northeastern Adams Township. Magnesite has been observed in several other exposures during the course of the 2003 bedrock mapping program, mainly located in northeastern Adams. The distinctive amber magnesium and iron carbonate minerals (magnesite, siderite, and limonite) are closely associated with the introduction of quartz in complicated arrays of *en échelon* veins in many of these occurrences. Magnesite occurrences exposed in the map area are not as magnesite-rich as the Canadian Magnesite deposit exposed in Deloro Township.

Silica

Unusually thick (up to 60 m) banded iron formation occurs in east-central Shaw Township and has been quarried as a source of silica flux for the smelting of base metals by Nortem Mining and Exploration Inc. Chert-dominated banded iron formation is the predominant lithology at this site. Quartz veins are associated with coarse-grained, euhedral pyrite mineralization where the veins intersect the iron-rich horizons. A very high proportion of silica (up to 99%) was obtained from surface grab samples. However, bulk sample analysis revealed lower (90%) purity silica. This discrepancy can be attributed to the leaching of the iron minerals from near-surface iron formation. The silica purity, however, can easily be increased with a magnetic separator to yield a more suitable flux.

RECOMMENDATIONS FOR EXPLORATION

Mining and exploration activities have increased over the past few years in the Shaw Dome area. Many of the rock types recognized in the area are correlated with rocks units that host gold, nickel, copper, and PGE mineralization throughout the Abitibi Subprovince.

Close spatial relationships between extrusive or intrusive ultramafic rocks (Supracrustal Package B and C) and sulphide-bearing iron formation (Supracrustal Package A and B) occur extensively along the margins of the Shaw Dome. The volume of komatiitic magma that interacted with an external sulphide source (the sulphide-bearing iron formation) is critical for komatiitic Ni-Cu-(PGE) mineralization. Abundant olivine cumulate indicates a high volume of magma, potentially sufficient to dissolve sulphur and precipitate sulphide minerals that carry the nickel, copper and PGE. The combination of abundant olivine cumulate (i.e., high magma flux) and its proximity to sulphide-bearing iron formation (i.e., a sulphur source) results in high exploration potential for komatiite-associated Ni-Cu-(PGE) deposits in the map area.

Numerous gold occurrences in the Shaw Dome demonstrate that gold mineralization is present south of the Porcupine–Destor deformation zone. Relatively little gold exploration has been carried out in this part of the Timmins camp for the last 20 or more years. The association between gold and iron formation is well established. There is an abundance of iron formation in the map area that has not been tested for gold mineralization.

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7. Project 00-010. Geology of Eby and Otto Townships, District of Timiskaming

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INTRODUCTION

Eby and Otto townships were mapped at a scale of 1:20 000 during the 2003 field season as a part of a multi-year project covering parts of 7 townships west of Kirkland Lake (Berger 2001; Berger and Leblanc 2002; Figure 7.1). The map area is approximately 180 km^2 and was mapped to improve the geological database and provide an impetus for mineral exploration. The town of Kenogami is located on Highway 11 in the north-central part of Eby Township and is approximately 15 km west of Kirkland Lake. Previous mapping by Dyer (1935) and Lovell (1972) identified the major rock types, structures and mineral occurrences; however, recognition of komatiites and the application of modern plate tectonic theory requires the re-evaluation of the area. Furthermore, the close proximity of the 2 townships to the Kirkland Lake gold camp emphasizes the need to advance our knowledge of the geology of the area. Technological improvements in geophysics and geographic information systems (GIS) were valuable tools used to fulfil this goal.

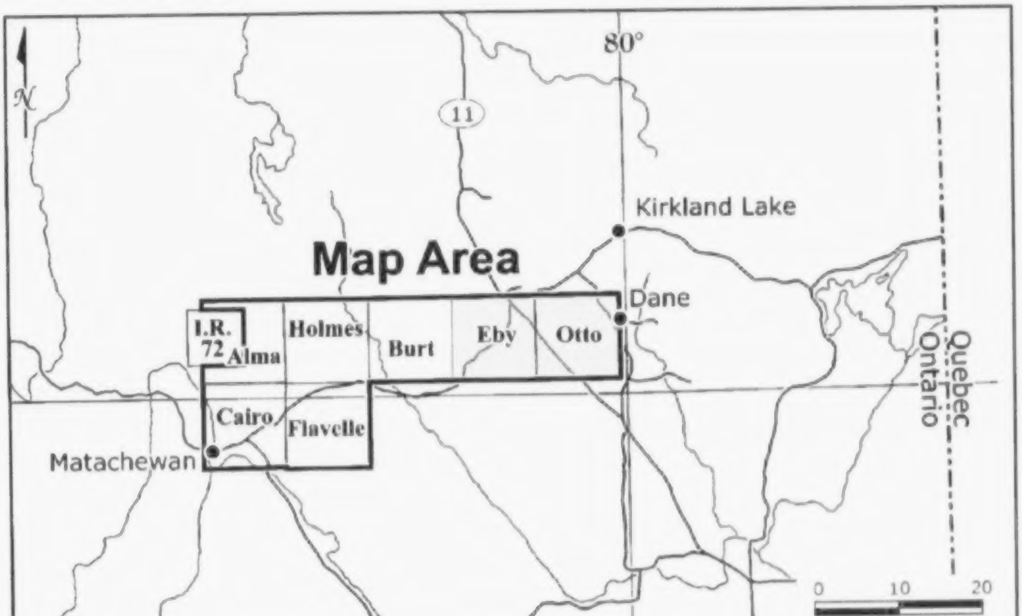

Figure 7.1. General location map for Eby and Otto townships.

Summary of Field Work and Other Activities 2003, Ontario Geological Survey, Open File Report 6120, p.7-1 to 7-8.

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GENERAL GEOLOGY

Eby and Otto townships are underlain by Neoarchean ultramafic, mafic, intermediate and felsic metavolcanic rocks, related intrusive rocks, Neoarchean clastic and chemical metasedimentary rocks and alkalic extrusive flows (Figure 7.2). These rocks are intruded by Archean felsic rocks of the Round Lake batholith, ultramafic, mafic and felsic alkalic rocks of the Otto stock and Paleoproterozoic diabase dikes of the Matachewan and possibly the Pressiac swarms (Osmani 1991). Clastic metasedimentary rocks correlated with the Proterozoic Gowganda Formation of the Cobalt Group of the Huronian Supergroup unconformably overlie the Archean rocks and Paleoproterozoic dikes of the Matachewan swarm. The western extension of the Larder–Cadillac deformation zone, a regional-scale structure spatially associated with gold mineralization extends through the north part of the map area.. The mapping helped to delineate and characterize the many structural components of the deformation zone and related structures.

Neoarchean Rocks

Ultramafic metavolcanic rocks occur south of Highway 66 in the northwest corner of Otto Township in the vicinity of Vigrass and Otto lakes (*see* Figure 7.2). The dark green to black weathering rocks are fine-grained, usually soft and may display randomly oriented and radiating or dendritic-like spinifex. The randomly oriented spinifex are composed of thin pyroxene and/or olivine blades that rarely exceed 15 mm in length, whereas, the radiating spinifex commonly have blades exceeding 50 mm in length. Other varieties of ultramafic flows include massive, pillowed, polysutured and flow breccia units.

Mafic metavolcanic rocks underlie much of Eby Township and the north part of Otto Township (*see* Figure 7.2). The majority of mafic metavolcanic rocks are dark green, massive, fine- to medium-grained rocks that are commonly recrystallized. Pillowed, variolitic and amygdaloidal flows are locally present. Most mafic metavolcanic rocks display low magnetic susceptibility; however, some magnetite-bearing units occur locally and are useful stratigraphic markers. Weak to intense pervasive carbonate alteration affects mafic metavolcanic rocks in the vicinity of the Larder–Cadillac deformation zone, west and south of Vigrass Lake and in the noses of regional folds. Gold may be present where green mica and sulphide minerals accompany carbonate alteration.

Felsic metavolcanic tuff, lapilli tuff and rare flows are interlayered with clastic metasedimentary rocks, and banded chert-magnetite iron formation in a narrow unit that crosses the central part of the map area (*see* Figure 7.2). The felsic rocks are fine grained, white to light pinkish grey on weathered surfaces and grey to dark grey on fresh surfaces. North and east of the Otto stock, extensive recrystallization makes identification of the protolith uncertain and rocks mapped as felsic metavolcanic may be chert or siliceous clastic metasedimentary rocks.

Finely laminated to thinly bedded magnetite and chert "iron formation" occurs interlayered with the felsic metavolcanic rocks described above. These units rarely exceed 2 m in thickness and are composed of 2 mm to 20 cm thick black magnetite beds separated by 1 cm to 30 cm thick white to grey chert beds. In northeast Otto Township, light brown garnet comprises up to 10% of the iron formation and indicates that rocks in this area attained higher amphibolite metamorphic grades. This type of iron formation extends to the Adams Mine, east of the map area, and is similar to sulphide-magnetite iron formation in Flavelle and Cairo townships west of the map area (Berger and Leblanc 2002).

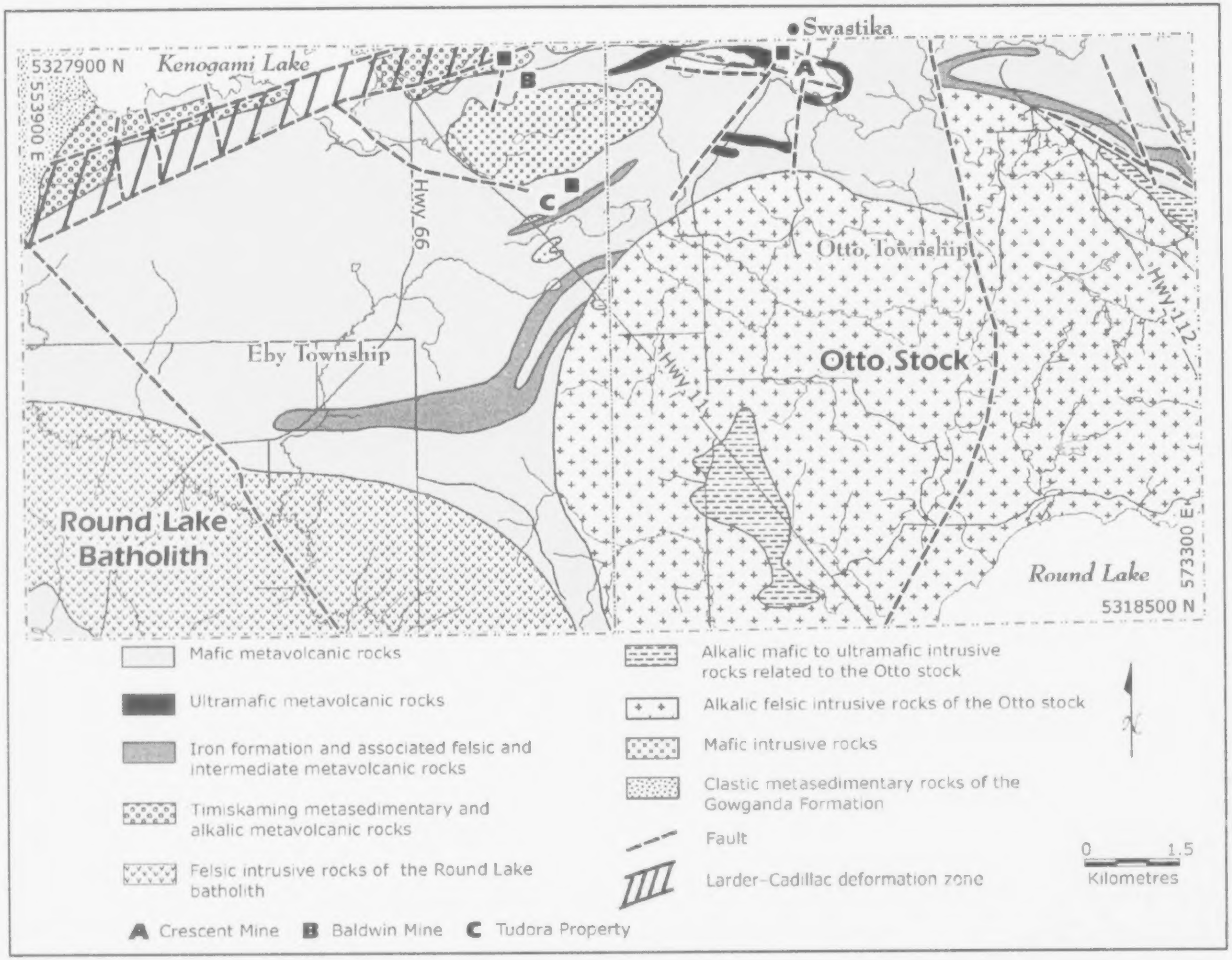
5327900 N
553900 E
Kenogami Lake
Swastika
A
B
C
Hwy 66
Eby Township
Otto Township
Otto Stock
Hwy 11
Hwy 112
Round Lake Batholith
Round Lake
573300 E
5318500 N
Mafic metavolcanic rocks
Ultramafic metavolcanic rocks
Iron formation and associated felsic and intermediate metavolcanic rocks
Timiskaming metasedimentary and alkalic metavolcanic rocks
Felsic intrusive rocks of the Round Lake batholith
Alkalic mafic to ultramafic intrusive rocks related to the Otto stock
Alkalic felsic intrusive rocks of the Otto stock
Mafic intrusive rocks
Clastic metasedimentary rocks of the Gowganda Formation
Fault
Larder–Cadillac deformation zone
N
0
1.5
Kilometres
A Crescent Mine
B Baldwin Mine
C Tudora Property

Figure 7.2. General geology of Eby and Otto townships.

Jasper-chert iron formation occurs interlayered with mafic metavolcanic flows in a few places in central Otto and northern Eby townships. This type of iron formation is commonly discontinuous and always narrow (less than 1 m thick). Its regional extent is unknown.

Alkalic metavolcanic rocks are interbedded with clastic metasedimentary rocks correlated with the Timiskaming assemblage and occur south and east of Kenogami Lake in Eby Township. The alkalic rocks are composed of aphanitic, fine-grained and amphibole and/or feldspar porphyritic flows, flow breccia, related subvolcanic dikes and sills. The rocks are light pink to reddish brown or deep earthy red and commonly display elevated magnetic susceptibilities. Specular hematite and magnetite are common accessory minerals.

Clast-supported polymictic conglomerate, fine-grained massive and cross-bedded sandstone and rare argillite are correlated with the Timiskaming assemblage in north Eby Township. Clasts in the conglomerate units are subangular to rounded and vary in size from 5 to 30 cm with an average size of about 6 cm. Several clast populations that include syenite, foid-bearing trachyte, quartz-feldspar porphyry intrusions, mafic metavolcanic, jasper, sulphide and mudstone/siltstone were identified. The matrix is usually dark green quartz and feldspar sand. The conglomerates are interbedded with narrow sandstone units and finely laminated wacke and argillite units. Primary structures are poorly preserved south of Kenogami Lake where the rocks are highly strained and sheared.

Small mafic intrusions, plugs, sills and dikes occur throughout the field area. The largest is located in northeast Eby Township and covers about 2 km^2. The intrusion is mostly composed of medium- to coarse-grained equigranular, weakly foliated gabbro, quartz gabbro and leucogabbro. The rock is light grey on weathered surface and dark green on fresh surface. In some cases, the rock is amphibole porphyritic with subhedral to euhedral rectangular phenocrysts that can reach up to 15 mm long. These rocks generally have low magnetic susceptibility.

Intermediate and felsic dikes, composed of quartz-feldspar porphyry, feldspar porphyry, intruded the metavolcanic and metasedimentary rocks throughout the map area. These dikes rarely exceed 1 m in width and are discontinuous along strike. Quartz-feldspar porphyry dikes are rare and contain 10 to 15%, 4 to 6 mm long subhedral to euhedral feldspar phenocrysts and about 5%, 3 to 5 mm long anhedral quartz phenocrysts. The feldspar porphyritic dikes contain about 30%, light pink, 3 to 4 mm long subhedral feldspar phenocrysts. The groundmass is composed of about 10 to 15% dark green subhedral to euhedral amphibole and light pink feldspar.

Neoarchean felsic intrusive rocks of the Round Lake batholith occur in southwest Eby Township. Grey to pink, medium- to coarse-grained, quartz and/or feldspar porphyritic, amphibole-bearing granodiorite is most common. The rock is massive to weakly foliated and is characterized by a low to moderate magnetic susceptibility. Tonalitic metatexite, diatexite and various types of gneiss are minor rock types in the map area, but are more abundant west of the map area. Harrap and Helmstaedt (1992) discuss the different phases and mechanism of intrusion of the Round Lake batholith in more detail.

The Otto stock occupies most of Otto Township and a small portion of eastern Eby Township. The intrusion contains numerous rock types, which display a wide range of compositions and textures; however, most of the intrusion is composed of medium- to coarse-grained, commonly alkali-feldspar (AF) porphyritic syenite. This light pink weathering rock commonly contains euhedral, tabular AF megacrysts up to 7 cm in length. Green to dark green amphibole is the major mafic mineral (5 to 15%) and biotite is rare. A medium-grained light pink inclusion-rich AF syenite unit is widespread in the east, south and southwest parts of the intrusion. The inclusions are dark green, rounded and commonly display a massive core that is surrounded by radiating fibrous amphibole crystals and a mica rim (Photo 7.1). The origin of these inclusions is uncertain, but they may represent an immiscible mafic to ultramafic liquid trapped in the syenite. Other felsic rocks that occur within the stock include light pink amphibole-bearing, medium-grained quartz-syenite and alkaline granite, which are both slightly AF porphyritic. An amphibole-rich AF megacrystic syenite commonly displaying a trachytic texture is interpreted to be magmatic in origin and was observed near the western contact of the intrusion. This rock is composed of 50 to 60% euhedral tabular feldspar megacrysts, which commonly display concentric zoning and Carlsbad twinning. The groundmass is primarily composed of dark green anhedral amphibole and anhedral to subhedral alkali-feldspar.

Rocks previously mapped as biotite-garnet-pyroxene amphibolite (Lovell 1972) are here interpreted to be mafic and ultramafic phases of the Otto stock and are best exposed along Highway 11 (*see* Figure 7.2). Dark grey to black, medium-grained, equigranular, mica-bearing alkalic gabbro to melagabbro is most common. The rock contains numerous mafic and ultramafic inclusions similar to those in the AF syenite as well as numerous country rock and rare gneissic xenoliths. In places, the mica content exceeds 50% of the rock and resembles lamprophyre observed in dikes throughout the map area. Cumulate-textured, coarse-grained, hornblendite also occurs along Highway 11 and is composed of 80 to 90% dark green to black subhedral to euhedral, 1 to 3 cm, amphibole crystals commonly with mica cores. Other mafic and ultramafic rock types observed in the Otto stock include clinopyroxenite, alkalic diorite and pegmatitic gabbro. Mafic and ultramafic rocks were also observed along the eastern and northern contacts of the Otto stock (*see* Figure 7.2).

Lamprophyre dikes are ubiquitous in the map area. Three types were observed. Amphibole-mica phyric and alkali feldspar-mica phyric dikes are localized within and near to the Otto stock. These dikes are generally narrow (less than 3 m wide), discontinuous along strike and rarely contain xenoliths. Dikes that contain 50% or more mica and abundant groundmass carbonate are numerous and occur throughout the map area. These lamprophyre dikes commonly contain xenoliths of country rock and syenite similar to that observed in the Otto stock.

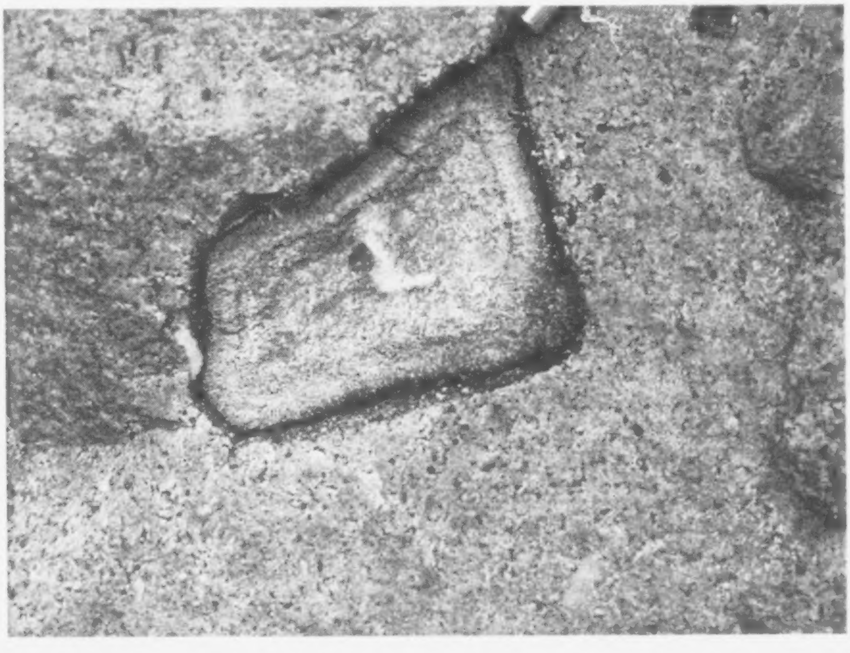

Photo 7.1. Mafic to ultramafic inclusion in the Otto stock alkali-feldspar syenite. The inclusion consists of a massive core surrounded by fibrous amphibole with a dark mica rim. Inclusion is approximately 8 cm in diameter.

Proterozoic Rocks

Numerous diabase dikes correlated with the Paleoproterozoic Matachewan swarm intruded all Archean rocks in the map area (Osmani 1991). Two types of dikes are recognized: plagioclase phyric dikes with phenocryst abundance greater than 1% and plagioclase aphyric dikes. Both types display moderate to high magnetic susceptibility. Lovell (1972) reported that diabase dikes that are correlated with either the Nipissing or Keweenawan swarm intruded the Otto stock and parts of the Timiskaming assemblage south of Kenogami Lake. These dikes resemble the Matachewan swarm, but display consistently lower magnetic susceptibility.

Clastic metasedimentary rocks correlated with the Gowganda Formation of the Cobalt Group of the Proterozoic Huronian Supergroup unconformably overlie all Archean rocks. They are well exposed in northern Eby Township along Highway 11 at Kenogami where polymictic conglomerate is interbedded with sandstone. The conglomerate is clast supported and contains granitic boulders up to 60 cm in diameter. Smaller clasts of mafic volcanic rocks, spinifex-textured ultramafic volcanic rocks, amphibole-rich tonalitic rocks, jasper and magnetite-chert are also present. The Gowganda Formation displays low-grade metamorphism and almost no deformation, which distinguishes it from Timiskaming assemblage rocks in the map area.

STRUCTURE AND METAMORPHISM

The map area is structurally complex and has undergone deformation in the Archean, the Proterozoic and most likely the Paleozoic (Lovell and Caine 1970).

Archean deformation is characterized by multiple phases of shearing, faulting and folding. The east-northeast-striking Larder–Cadillac deformation zone is the most prominent structural feature in the northern part of the map area. The deformation zone is marked by intensely schistose rock along the south shore of Kenogami Lake, at several locations south of the lake and in discrete faults along Highway 66 in Otto Township. Mineral lineations, slickenlines and "stepping" document complex sinistral and dextral movements, but generally show south-side-up vertical movement on fault planes. A S_1 foliation strikes 065 to 080° in the deformation zone and is consistently overprinted by a S_2 foliation that strikes 055 to 035°. North-northeast- and northwest-striking faults cross and locally offset the main trace of the deformation zone. Gold mineralization is localized near these cross faults at the Baldwin and Crescent mines (*see* Figure 7.2).

Folding is complex. Regional-scale fold axes are subparallel to S_1 in Otto and central Eby townships and are northwest-striking in north Eby Township. Fold axes appear to be offset by the late cross faults and are deflected around the contacts of the Otto stock. Gold and base metal mineralization is preferentially sited in the noses of some of these folds.

The Amikougami fault is a major north-striking structure that sinistrally offsets the north contact of the Otto stock by 2 km and separates different phases of the stock. The majority of undersaturated felsic alkalic rocks occur east of the fault, whereas, quartz-bearing alkalic rocks are most abundant west of the fault. Like many similarly oriented faults elsewhere in the Abitibi greenstone belt, the authors believe that the Amikougami fault is an Archean structure that was reactivated during the Proterozoic and possibly during the Paleozoic rift valley event (Berger 2002; Lovell and Caine 1970). Locally, a spaced foliation occurs in members of the Gowganda Formation parallel to foliation in the underlying Archean rocks and indicates Proterozoic reactivation (Powell and Hodgson 1992).

Regional greenschist-grade metamorphic mineral assemblages is characterized by epidote, chlorite and albite in mafic metavolcanic rocks. However, these rocks are extensively recrystallized adjacent to the Round Lake batholith and the Otto stock. Epidote stringers, feldspar porphyroblasts, garnet and secondary amphibole are common in mafic metavolcanic rocks and, locally, partial melting was attained as evidenced by quartz-feldspar stringers. The contact thermal halo around the Otto stock extends up to 1 km in width and rarely biotite occurs in intermediate and mafic metavolcanic rocks, indicative of widespread metasomatism. The thermal halo associated with the Round Lake batholith is up to 300 m wide. Numerous feldspar porphyritic tonalite dikes are intruded along foliation planes and locally extend the thermal aureole up to 500 m from the contact of the batholith.

Epidote, chlorite and rare biotite in sandstone and argillite indicate that the Gowganda Formation was subjected to low-grade metamorphism possibly related to some of the diabase dikes in the map area.

RECOMMENDATIONS FOR EXPLORATION

Gold has been the main target of exploration in the map area. Like most gold occurrences in the Kirkland Lake area, gold deposits in Eby and Otto townships are spatially associated with the Larder–Cadillac deformation zone. The past-producing Crescent Mine, located on the northwest shore of Otto Lake, and the past-producing Baldwin Mine, located in the northeast corner of Eby Township, had limited production (Lovell 1972). Gold occurs in quartz veins in proximity to northeast-striking faults at both deposits. Explorationists should look for similar environments, especially where these faults cross the Larder–Cadillac deformation zone. Gold mineralization also occurs south of the main deformation zone and appears to be focussed at the nose of tight regional-scale folds (e.g., the Tudora property in Eby Township). The mafic to ultramafic rocks related to the Otto stock offer interesting prospects for nickel-copper and platinum group elements (PGE) mineralization. Copper, gold and elevated PGE values were obtained from samples of malachite-bearing hornblendite collected along a roadcut on Highway 11 (Berger 2001). These rocks display some similarities to xenolith-rich ultramafic units and heterolithic breccias in the Wawa area that are known to contain diamonds (Stott, Wilson and Grabowski 2002). Further exploration work on these rocks is highly recommended.

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8. Project Unit 96-003. Geology of the Shining Tree South Area

G.W. Johns[1]

[1]Precambrian Geoscience Section, Ontario Geological Survey

INTRODUCTION

Except for the eastern half of North Williams and Dufferin townships and the eastern third of Stull Township (Card, McIlwaine and Meyn 1973), the area south of the Shining Tree greenstone belt has not been previously mapped by the Ontario Geological Survey. Recent work by local prospectors has discovered base metal mineralization in the metavolcanic rocks. These metavolcanic rocks are more extensive and comprise a wider range of rock types (Assessment Files, Resident Geologist's Office, Kirkland Lake) than that portrayed on the compilation map by Card and Lumbers (1977). In order to better understand the setting of the mineralization and the extent of the metavolcanic rocks, a reconnaissance geological survey of the area was undertaken.

The project area comprises the 12 townships of Garibaldi, Sheard, Ogilvie, North Williams, Moffat, Amyot, Browning, Dufferin, Beulah, Hodgetts, Unwin and Stull mapped at a reconnaissance scale of 1:50 000. The area is 100 km north of Sudbury and adjoins the Shining Tree area (Johns 2003) to the north (Figure 8.1).

An extensive system of active and inactive logging roads were used to access the area. Approximately 30% of the area was not examined due to either a lack of road access or to an extensive cover of Pleistocene deposits.

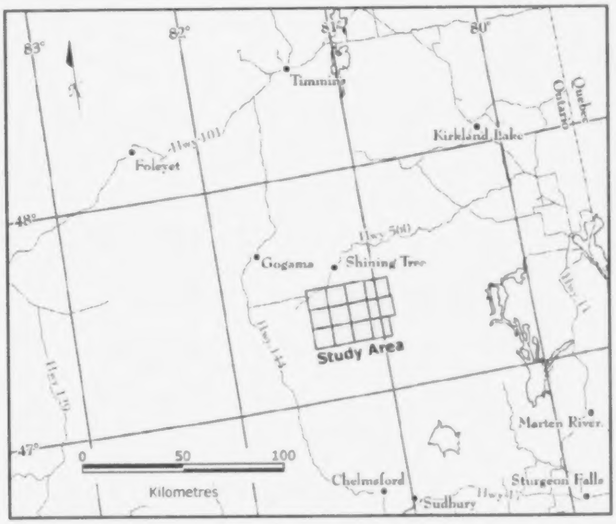
83°
82°
81°
80°
48°
47°
Timmins
Kirkland Lake
Quebec
Ontario
Foleyet
Hwy 101
Hwy 560
Gogama
Shining Tree
Hwy 11
Hwy 144
Study Area
Hwy 129
Marten River
0
50
100
Kilometres
Chelmsford
Sudbury
Hwy 17
Sturgeon Falls

Figure 8.1. Location of the Shining Tree south study area.

Summary of Field Work and Other Activities 2003,
Ontario Geological Survey, Open File Report 6120, p.8-1 to 8-11.

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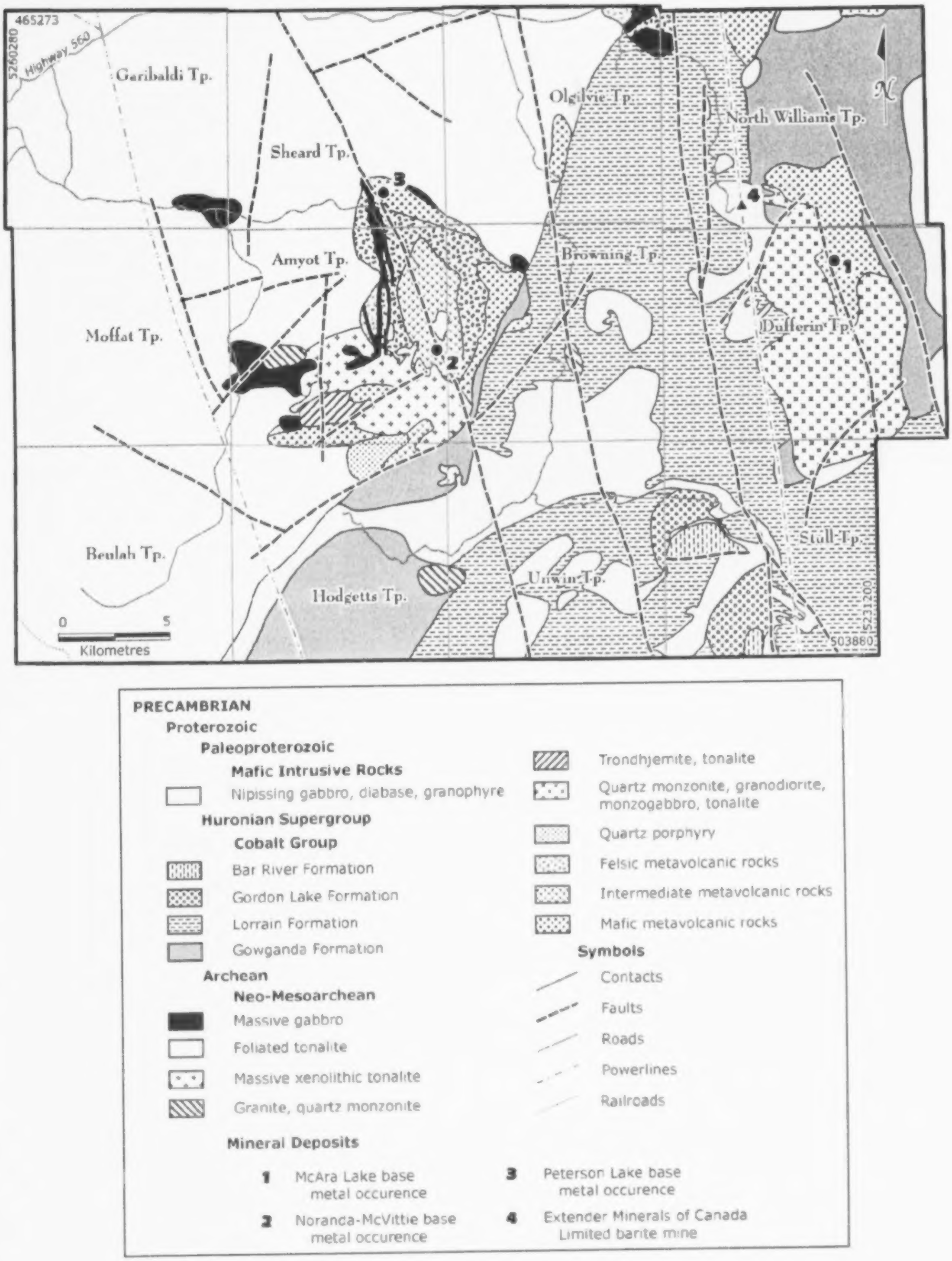
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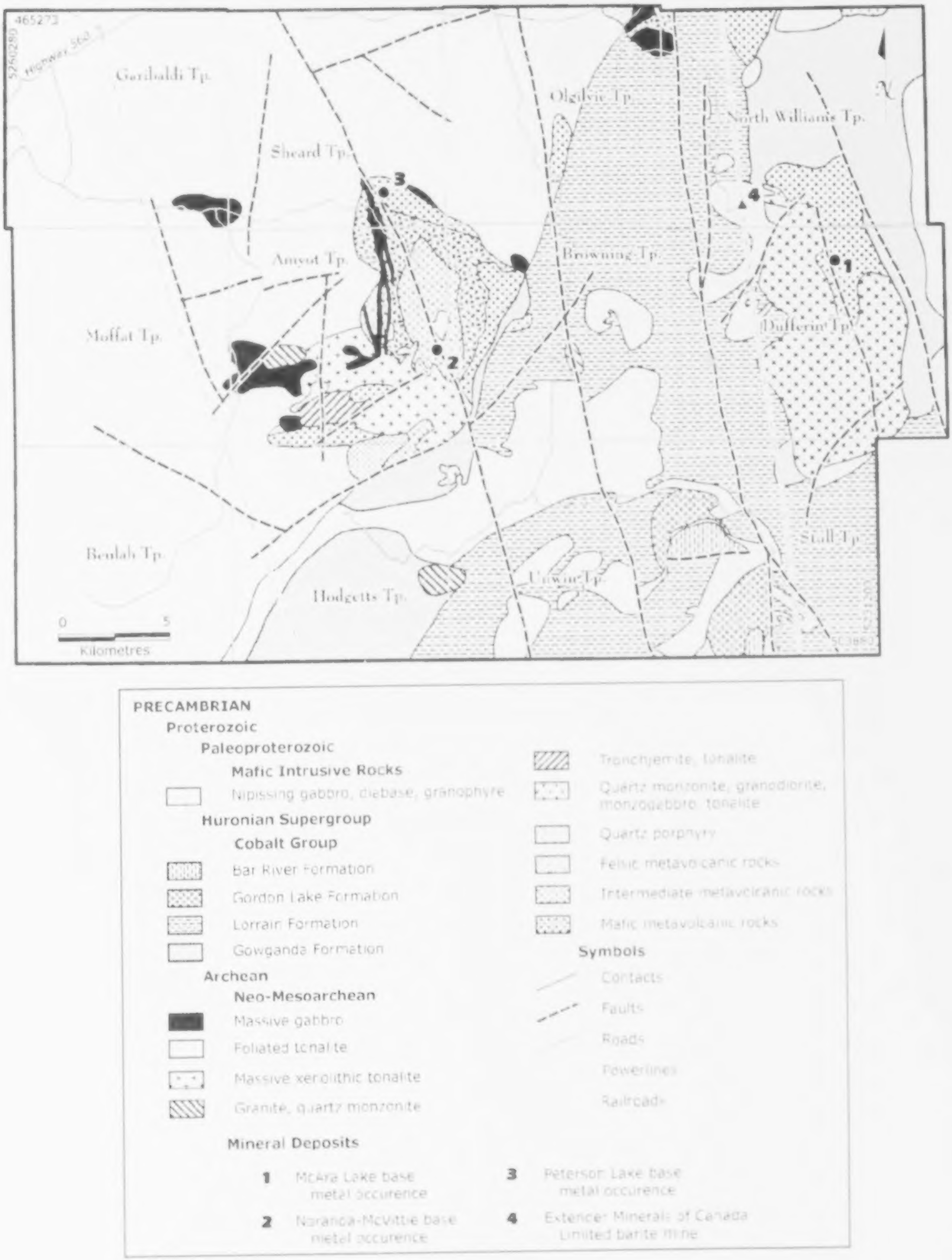
Highway 560
Garibaldi Tp.
Sheard Tp.
Olgilvie Tp.
North Williams Tp.
N
Amyot Tp.
Browning Tp.
Moffat Tp.
Dufferin Tp.
Beulah Tp.
Hodgetts Tp.
Unwin Tp.
Stull Tp.
5231200
503880
0
5
Kilometres
1
2
3
4
PRECAMBRIAN
Proterozoic
Paleoproterozoic
Mafic Intrusive Rocks
Nipissing gabbro, diabase, granophyre
Huronian Supergroup
Cobalt Group
Bar River Formation
Gordon Lake Formation
Lorrain Formation
Gowganda Formation
Archean
Neo-Mesoarchean
Massive gabbro
Foliated tonalite
Massive xenolithic tonalite
Granite, quartz monzonite
Trondhjemite, tonalite
Quartz monzonite, granodiorite, monzogabbro, tonalite
Quartz porphyry
Felsic metavolcanic rocks
Intermediate metavolcanic rocks
Mafic metavolcanic rocks
Symbols
Contacts
Faults
Roads
Powerlines
Railroads
Mineral Deposits
1 McAra Lake base metal occurence
2 Noranda-McVittie base metal occurence
3 Peterson Lake base metal occurence
4 Extender Minerals of Canada Limited barite mine

Figure 8.2. Geology of the Shining Tree south area.


465273
5240280
Highway 560
Garibaldi Tp.
Sheard Tp.
Ogilvie Tp.
North Williams Tp.
Amyot Tp.
Browning Tp.
Moffat Tp.
Dufferin Tp.
Beulah Tp.
Hodgetts Tp.
Unwin Tp.
Stull Tp.
N
1
2
3
4
0 5
Kilometres
PRECAMBRIAN
Proterozoic
Paleoproterozoic
Mafic Intrusive Rocks
Nipissing gabbro, diabase, granophyre
Huronian Supergroup
Cobalt Group
Bar River Formation
Gordon Lake Formation
Lorrain Formation
Gowganda Formation
Archean
Neo-Mesoarchean
Massive gabbro
Foliated tonalite
Massive xenolithic tonalite
Granite, quartz monzonite
Trondhjemite, tonalite
Quartz monzonite, granodiorite, monzogabbro, tonalite
Quartz porphyry
Felsic metavolcanic rocks
Intermediate metavolcanic rocks
Mafic metavolcanic rocks
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1 McAra Lake base metal occurence
2 Noranda-McVittie base metal occurence
3 Peterson Lake base metal occurence
4 Extender Minerals of Canada Limited barite mine

Figure 8.2. Geology of the Shining Tree south area

Table 8.1. Table of major element geochemistry of selected supracrustal rocks in the Shining Tree south area.

Sample Number	**03-GWJ-043**	**03-GWJ-044**	**03-GWJ-045**	**03-GWJ-085**	**03-GWJ-116**	**03-GWJ-123**	**03-GWJ-131**	**03-GWJ-136**	**03-GWJ-138**
Rock Type[a]	Mafic volcanic	Inter. volcanic	Inter. volcanic	Mafic volcanic	Mafic volcanic	Felsic volcanic	Mafic intrusion	Mafic intrusion	Mafic intrusion
Easting[b]	498171	498170	498393	489988	482825	483809	481195	478250	474988
Northing[b]	5260296	5260247	5258068	5255280	5252129	5241691	5244747	5241976	5243842
SiO_2	50.66	57.83	57.46	47.30	49.83	68.55	48.81	53.52	52.80
TiO_2	2.20	0.78	0.94	0.73	1.13	0.49	1.46	1.52	0.36
Al_2O_3	13.81	17.03	16.56	17.13	13.87	15.52	13.88	13.11	5.59
Fe_2O_3	16.23	7.25	7.98	12.35	14.87	2.82	16.28	14.09	10.76
CaO	8.33	3.26	4.78	9.13	10.40	2.53	9.45	6.11	12.27
K_2O	0.37	0.40	1.22	1.14	0.59	1.68	0.54	2.88	0.27
Na_2O	2.03	6.39	6.87	1.93	1.98	5.00	2.09	3.12	1.03
MgO	5.35	3.63	3.03	9.08	6.73	2.00	5.92	3.97	15.52
MnO	0.24	0.12	0.14	0.18	0.23	0.02	0.24	0.19	0.19
P_2O_5	0.21	0.43	0.23	0.05	0.09	0.12	0.10	0.17	0.02
LOI	1.87	3.41	1.33	2.36	1.49	1.46	2.12	2.05	1.58
Total	101.31	100.53	100.54	101.38	101.20	100.18	100.89	100.73	100.38

[a] Inter. volcanic, intermediate volcanic

[b] Universal Transverse Mercator coordinates in North American Datum 1983, Zone 17

GENERAL GEOLOGY

The area is underlain by Archean tonalites and mafic to felsic metavolcanic rocks both of which have been intruded by metagabbro. All are overlain by Proterozoic, Huronian Supergroup metasedimentary rocks, which are intruded by Nipissing gabbro to granophyric gabbro (Figure 8.2). Base metal mineralization is found in felsic metavolcanic rocks and quartz porphyry in Sheard, Amyot and Browning townships and in interflow metasedimentary and mafic metavolcanic rocks in Dufferin and North Williams townships. Major element geochemistry of Archean metavolcanic rocks and mafic intrusions are found in Table 8.1.

Archean

METAVOLCANIC ROCKS

Two significant areas of metavolcanic rocks were noted. A mafic flow to felsic pyroclastic succession of rocks occurs in southeast Sheard, northeast Amyot and northwest Browning townships. Mafic flows with interflow metasedimentary rocks are found in southern North Williams and northern Dufferin townships. As well as these coherent packages, scattered outcrops of metavolcanic rock are found as inliers within the Huronian Supergroup metasedimentary rocks. In southern Amyot and northern Hodgetts townships, discontinuous mafic and felsic metavolcanic rocks intruded by synvolcanic quartz porphyry to trondhjemite have been intruded by tonalite and metagabbro (*see* Figure 8.2).

Mafic metavolcanic rocks predominate in Dufferin and North Williams townships where they are fine to medium grained, foliated and metamorphosed to amphibolite facies. Few pillowed flows were observed. In southeast Sheard Township, mafic metavolcanic rocks are dark green, medium grained, massive and intruded by mineralized, white, quartz porphyry. The mafic rocks may be, in part, synvolcanic gabbro intrusions. In southern Amyot and northern Hodgetts townships, fine-grained to medium-grained mafic metavolcanic rocks occur as xenoliths and blocks within massive hornblende tonalite.

Intermediate metavolcanic rocks occurring in northeastern Amyot Township were not observed by the author, but previous observations were compiled from assessment files (Assessment Files, Resident Geologist's Office, Kirkland Lake). Minor, fine-grained, intermediate, pyroclastic rocks were observed in western North Williams Township as inliers in the Huronian Supergroup metasedimentary rocks.

Quartz phyric, felsic pyroclastic metavolcanic rocks, noted in diamond-drill logs (Assessment Files, Resident Geologist's Office, Kirkland Lake), are found in Sheard, Amyot and Browning townships. Outcrops of felsic to intermediate metavolcanic rocks occur in southeastern Amyot Township and are generally white, very fine grained and massive. Quartz porphyry to fine-grained trondhjemite also occur in the same area. They may be related to the quartz phyric felsic metavolcanic rocks seen in diamond drill core and the quartz porphyry intruding the mafic metavolcanic rocks at Peterson Lake.

METAMORPHOSED MAFIC INTRUSIVE ROCKS

Metamorphosed gabbro cuts both the massive and foliated tonalite and is intruded by later phase granodiorite, aplite and pegmatite. The gabbro is massive, unfoliated and ranges in grain size from fine to coarse. Textures range from equigranular to mottled with varied grain sizes. Some outcrops display mineral banding with sharp to gradational contacts. A coarse-grained melanogabbro found on the border of Amyot and Moffat townships contains about 10% clear anhedral quartz.

METAMORPHOSED INTERMEDIATE TO FELSIC INTRUSIVE ROCKS

Quartz porphyry intrudes metavolcanic rocks and metagabbro. In southeastern Sheard Township, quartz porphyry intrudes medium-grained, massive metavolcanic rocks. These rocks are highly sheared and mineralized with chalcopyrite, sphalerite and galena. In the southern part of Amyot Township, quartz porphyry intrudes mafic to intermediate metavolcanic rocks.

INTERMEDIATE TO FELSIC INTRUSIVE ROCKS

Intermediate to felsic intrusive rocks underlie approximately 50% of the map area. The predominant rock type is a biotite to hornblende, quartz-rich tonalite. Two phases of tonalite are found: a foliated phase that encompasses the northwest portion of the area and a massive phase centred on Amyot Township. The foliated phase is generally white, medium grained, with foliation being accentuated by elongated quartz grains surrounding subhedral to euhedral feldspar. Biotite comprises the majority mafic mineral and is generally fine grained and flattened along the foliation plane. Euhedral to subhedral hornblende comprises a minor constituent. The massive phase intrudes the metavolcanic rocks in southern Amyot Township and separates them from the metavolcanic rocks to the north. This massive phase also contains xenoliths of supracrustal rocks and mafic mineral content varies between biotite-rich to hornblende-rich phases. Later dikes of fine-grained granodiorite and aplite, as well as pegmatite, intrude the tonalite and postdate the metagabbro.

Pink, massive, medium-grained, potassium feldspar phyric, quartz monzonite intrudes the tonalite and metagabbro in southwest Amyot Township. A massive medium-grained, dark pink, hornblende quartz monzonite is found in northern Dufferin Township. In northern Stull and southern Dufferin townships, a foliated biotite granodiorite is exposed.

MAFIC INTRUSIVE ROCKS

North-northwest-trending, magnetic, diabase dikes intrude all Archean rocks. These massive, equigranular dikes are interpreted to be part of the Paleoproterozoic Matachewan dike swarm. They weather dark brown and have a dark grey to black fresh surface. Patches and veins of epidote alteration are also characteristic.

Proterozoic

Proterozoic rocks cover approximately 40% of the map area, mainly in the east and southeast parts, all of which are intruded by Nipissing gabbro sills and dikes. Proterozoic metasedimentary rocks in the area are assigned to the Gowganda, Lorrain, Gordon Lake and Bar River formations of the Huronian Supergroup. The Lorrain Formation is the most extensive unit followed by the Nipissing gabbro sills. Long and Colvine (1984, 1985) examined the Huronian Supergroup in the area for alluvial paleoplacer gold potential.

HURONIAN SUPERGROUP

Gowganda Formation

Gowganda Formation conglomerate, arenite and argillite unconformably overlie the Archean rocks. It is found both as relatively thin continuous units and as isolated outcrops overlying tonalite. The formation comprises an interbedded mixture of coarse, heterolithic conglomerate, pebble wacke, thinly bedded argillite and minor arenite. In northeast Hodgetts Township, interbedded, thinly laminated argillite and pebbly wacke unconformably overlie a massive Archean tonalite. The tonalite under the Gowganda Formation is not weathered or brecciated indicating that weathering of the Archean rocks did not occur prior to deposition. Long and Leslie (1982) note that part of this formation may have been deposited in a subglacial environment, but most of the formation appears to have been deposited in a deep-water environment with very little glacial influence.

In north-central Hodgetts Township, fine-grained, massive wacke and argillite with minor drop stones are found. Within this fine-grained sequence, there is a synsedimentary breccia consisting of pink silty arenite in an argillaceous matrix (Photo 8.1). The clasts are randomly oriented and the matrix is massive in appearance. This breccia is associated with soft sediment deformation and may be related to tectonic-induced slumping.

Lorrain Formation

The Lorrain Formation both overlies the Gowganda Formation and unconformably overlies the Archean. Rocks of the formation crop out on the east to southeast side of the map area thickening from north to south. The Lorrain Formation is composed of several members that were not subdivided during this project. It comprises thickly bedded quartz arenite ranging from white to pale green to pink. The quartz arenite is immature with subrounded to subangular coarse to fine quartz grains. Minor quartz and chert pebble conglomerate beds are found in the white and pale green quartz arenite and the thick beds also contain isolated quartz pebbles. The thick beds are generally featureless, but large-scale cross-beds can be found.

Gordon Lake Formation

The Gordon Lake Formation can be found in the Welcome Lake area in southern Stull Township and is up to 100 m thick. The formation is composed of centimetre-scale beds of red, fine-grained feldspathic arenite, green to buff siltstone and green chert. The chert beds are commonly brecciated and soft sediment deformation, flame features and ball-and-pillow structures are common between the siltstone, chert and arenite. The contact with the Lorrain Formation was not observed and a Nipissing gabbro sill obscures the upper contact.

Chlorite spotting is a common alteration pattern in these rocks north of Welcome Lake in Stull Township. The source of the alteration is the Nipissing gabbro sill that intrudes the unit along the lower contact.

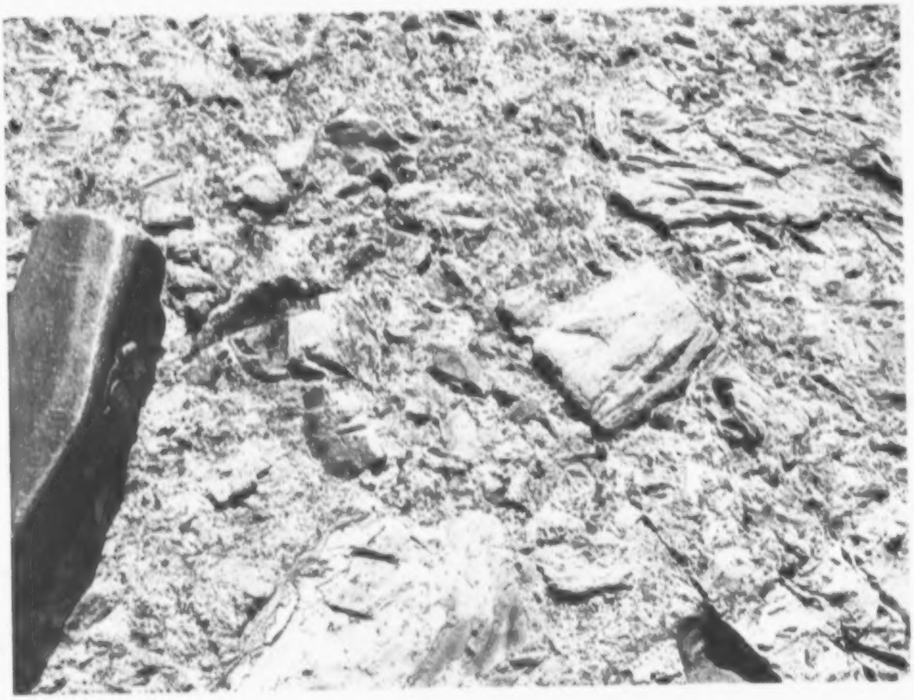

Photo 8.1. Synsedimentary breccia in the Gowganda Formation. Angular light red silt clasts supported in a green argillite matrix.

Bar River Formation

The Bar River Formation overlies the Gordon Lake Formation and is preserved in the core of the Welcome Lake syncline in Valin Township, south of the map area. It is similar in appearance to the Lorrain Formation and is about 125 m thick (Long and Colvine 1985). It is composed of thick bedded, to massive, white, fine-grained quartz arenite.

Nipissing Gabbro

Nipissing gabbro occurs as sills and dikes intruding metasediments of the Huronian Supergroup. It is fine to medium grained with a greenish buff weathered surface and a grey to grey-green fresh surface. In the Welcome Lake area, the Nipissing gabbro is magnetic and contains minor disseminated pyrite. The tops of some of the sills are more felsic in appearance. They have a pinkish weathered surface and contain minor quartz, and are a granophyric gabbro. Although younger than the Matachewan diabase dikes, they are more highly altered. This may be due to the higher volatile content of the sills. Sill thickness is unknown throughout most of the area, but, in the Welcome Lake area, a sill was observed to be in the range of 50 to 100 m thick.

The sills are intruded parallel to the sedimentary stratigraphy and have gentle dips. Photo 8.2 shows the undulatory nature of a sill that has patches of baked Lorrain Formation along the top of the outcrop.

STRUCTURAL GEOLOGY

Metavolcanic rocks in Sheard, Amyot, Browning, North Williams and Dufferin townships are interpreted to trend in a northerly direction. Stratigraphic symmetry in Sheard, Amyot and Browning townships may indicate a north-trending fold axis of unknown form. Bedding in the Huronian Supergroup is generally varied with shallow dips, which may represent the underlying paleotopographic relief.

Metavolcanic rocks in Sheard, Amyot and Browning townships are similar in appearance to metavolcanic rocks of the Pacaud assemblage found in the Shining Tree area to the north (Johns and Amelin 1999) and may be correlative. Metavolcanic rocks in North Williams and Dufferin townships are correlated with the Deloro assemblage, which is found directly to the north in the Shining Tree area (Johns and Amelin 1999).

Steep to vertical dipping foliation in the intermediate to felsic intrusive tonalite is approximately concentric around an unfoliated central tonalite core centred on Amyot Township. The central core is composed of massive medium-grained, metavolcanic xenolith-bearing tonalite that intrudes the metavolcanic rocks.

Two prominent, regional fault sets are observed in the area: a northeast-trending set and a younger north-northwest-trending set. The north-northwest fault set has been correlated with the Lake Timiskaming rift system and cuts all ages of rocks in the map area.

The stratigraphy of the Huronian Supergroup in the northern part of the area is gently dipping in several directions. This indicates that the sediments have not undergone significant deformation and represent the underlying Archean paleotopography upon which they were deposited. In the southeast part of the area, in the vicinity of Welcome Lake, dips are steeper and a synclinal fold axis was noted south of the area (Long and Colvine 1986).

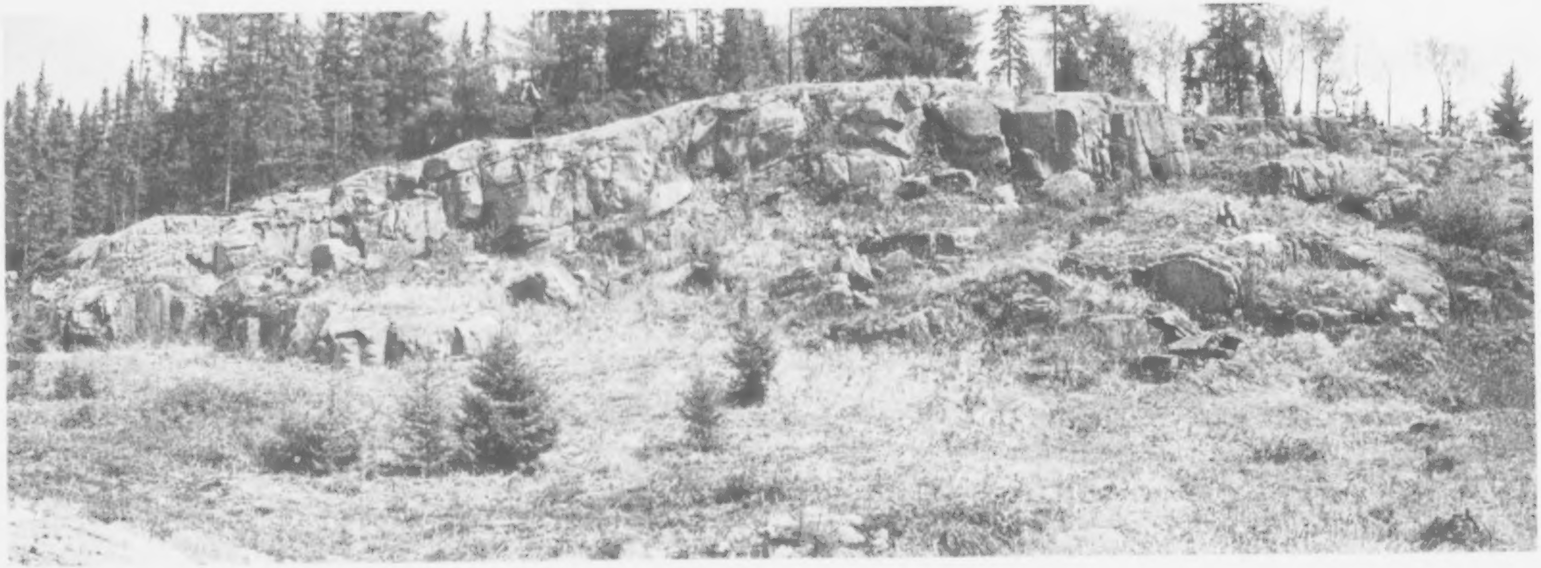

Photo 8.2. Nipissing gabbro sill showing the curvilinear nature of the contacts with the Lorrain Formation. The top of the outcrop contains patches of Lorrain Formation "baked" by contact with the sill.

ECONOMIC GEOLOGY

The area has had an active exploration history for base metals, barite, silver-cobalt and gold (Table 8.2).

Table 8.2. Mineral occurrences listed in the Mineral Deposit Inventory for the Shining Tree south area.

Name	Status	Commodity	Township	MDI #	Easting	Northing
Annett–Tindale property (McVittie–Noranda #2 showing)	Oc	Cu, Au	Amyot	MDI41P06SE00011	484292	5244305
Annett–Tindale property (Welch–Calloway showing)	Oc	Cu	Amyot	MDI41P06NE00009	483605	5246640
Beulah Township Placer #1	Mo	Au	Beulah	MDI41P06SW00003	469713	5239402
Meteor Lake	Oc	Au	Beulah	MDI41P06SW00002	471113	5236686
Annett–Tindale property	Oc	Cu, Pb, Zn, Au	Browning	MDI41P06SE00019	486360	5246190
John L. Tindale	Oc	Cu	Browning	MDI41P06SE00018	491960	5245875
Rosie Creek	Di	Ag	Browning	MDI41P06SE00009	491250	5243569
Annett–Salo property	Oc	Barite, Cu	Dufferin	MDI41P06NE00011	498440	5248100
Annett–Salo property	Oc	Cu	Dufferin	MDI41P06SE00017	498650	5246150
Ranex	Di	Au, Ag	Hodgetts	MDI41P06SW00004	477275	5234020
Seldore	Oc	Cu, Fe	Hodgetts	MDI41P06SE00010	482515	5233620
Annett–Salo property	Oc	Cu	North Williams	MDI41P06NE00012	497620	5250750
Falconbridge Ltd. (Lacarte property)	Oc	Cu, Au	North Williams	MDI41P06NE00014	496460	5253430
Racket Lake	Oc	Au	North Williams	MDI41P06NE00003	497927	5252982
Roy Lacarte property	Oc	Cu	North Williams	MDI41P06NE00013	499180	5258125
Silvester Creek	Oc	Ag	North Williams	MDI41P06NE00008	496457	5252081
Tracey Lake (Extender Minerals)	Mr	Barite, Cu	North Williams	MDI41P06NE00005	497961	5251182
Utah	Oc	Au	Ogilvie	MDI41P06NE00002	491515	5250891
Annett–Tindale property (Peterson Lake #2 showing)	Oc	Zn, Pb, Cu	Sheard	MDI41P06NE00010	481950	5251700
Stull Barite	Oc	Barite, Cu	Stull	MDI41P06SE00016	496300	5238100
Chicault gold-cobalt	Di	Ag, Au, Co	Unwin	MDI41P06SE00004	489861	5233678
Rosie Creek	Di	Barite, Cu	Unwin	MDI41P06SE00007	491251	5239763
Saturday Lake	Oc	Co	Unwin	MDI41P06SE00014	492973	5239761
White Lake	Oc	Ni, Ag, Co	Unwin	MDI41P06SE00013	492739	5238461

Note: Universal Transverse Mercator coordinates in North American Datum 1927 (NAD27), Zone 17.
Abbreviations: Di, discretionary occurrence; Oc, occurrence; Mr, Mine with reserves; Mo, Mine without reserves.

Base metal mineralization is found in the felsic to mafic metavolcanic rocks in Browning, Sheard and Amyot townships and in metasedimentary rocks within mafic metavolcanic rocks in North Williams and Dufferin townships (*see* Figure 8.2). Both of these areas have undergone active exploration in the past (Assessment Files, Resident Geologist's Office, Kirkland Lake).

Barite is currently being mined underground at Tracy Lake by Extender Minerals of Canada Limited. Several other showings of barite are found in veins cutting Nipissing gabbro throughout the area.

Base Metal Mineralization

In Sheard, Amyot and Browning townships, sulphide mineralization is found mainly as massive and stringer pyrite in felsic metavolcanic rocks. The best showings are the Peterson Lake and McVittie–Noranda showings (*see* Table 8.2). The Peterson Lake showings in Sheard Township have 0.01 to 0.44% Cu, 0.23 to 1.08% Zn and 0.14 to 3.0% Pb in sheared quartz porphyry intruding coarse mafic metavolcanic flows. The Noranda–McVittie showings in southeast Amyot Township are in intermediate metavolcanic flows and contain 2.28 to 2.53% Cu, 0.04% Zn, 0.08% Pb and 223 ppb Au (Assessment Files, Resident Geologist's Office, Kirkland Lake).

In northern Dufferin Township, graphitic and cherty argillite contains massive to disseminated pyrite, chalcopyrite and sphalerite (McAra Lake). The sulphide-bearing zone is about 3 km long by 100 to 200 m wide, striking northwest within mafic metavolcanic flows. The sulphide mineralization occurs as massive and streaks of pyrite, pyrrhotite, chalcopyrite and sphalerite. The best assay was from a 2 m long chip sample which analyzed 1.04% Cu, 1.98% Pb and 1.84% Zn. A diamond-drill intersection of 0.76% Cu over 9.2 m was noted (Assessment Files, Resident Geologist's Office, Kirkland Lake).

Barite

A 2 to 3 m wide barite vein is currently being mined at Tracy Lake by Extender Minerals of Canada Limited. The vein is Proterozoic in age and crosscuts Nipissing gabbro. Several barite veins in the area are related; all with a strike of 40° and with asymmetric red alteration. The alteration is brick red in colour and has a macroscopic appearance of fine-grained syenite. Contacts with the unaltered gabbro are gradational. The barite veins in the area form in clusters with a larger vein associated with smaller veins (Roy Annett, Prospector, personal communication, 2003).

Huronian Supergroup

Long and Colvine (1984, 1985) examined the Huronian Supergroup in the current map area looking for evidence of paleoplacer gold. The most favourable host for paleoplacer gold deposits is in the hematitic member of the Lorrain Formation. The highest concentration of gold was 1060 ppb Au (Long and Colvine 1985) found at Racket Lake in North Williams Township (*see* Table 8.2). The auriferous bed did not contain visible heavy mineral bands and had only local hematite staining (Long and Colvine 1985). In general, analytical results reported from the Long and Colvine study (1985) indicate 5 of 12 samples from the Gowganda Formation contained 2 to 7 ppb Au; 15 of 73 samples from the Lower Lorrain Formation contained 2 to 10 ppb Au; 30 of 71 samples from the middle member contained 2 to 1060 ppb Au; 22 of 70 samples from the upper member contained 2 to 7 ppb Au. Analyses of 7 of 26 samples from the Gordon Lake Formation contained 2 to 6 ppb Au, and only 1 of 9 samples from the Bar River Formation contained gold (3 ppb Au).

RECOMMENDATIONS FOR EXPLORATION

Archean metavolcanic rocks have potential to host massive sulphide mineralization. Mineralization may be remobilized around northwest-trending regional faults and Sheard, Amyot, North Williams and Dufferin townships are have the potential to host base metal mineralization.

A northeast-trending deformation zone in northern Hodgetts and Browning townships should be prospected for lode-gold deposits.

Proterozoic-age rocks are potential targets for barite, silver and cobalt and gold exploration. Nipissing gabbro hosts the Extender Minerals of Canada Limited barite mine and other barite occurrences also occur within the gabbro. The barite veins occur in sets and have a distinctive red alteration. Silver and cobalt mineralization is commonly found associated with Nipissing gabbro where it has intruded into the Huronian Supergroup and Archean rocks.

Long and Colvine (1985) concluded that the best place to prospect for paleoplacer gold in the Huronian Supergroup is in the middle hematitic member of the Lorrain Formation in North Williams Township.

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9. Project Unit 03-002. Synthesis of Archean Geology and Diamond-bearing Rocks in the Michipicoten Greenstone Belt: Geology of Menzies Township

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INTRODUCTION

An increase in the number and significance of diamond discoveries in Archean rocks of the Michipicoten greenstone belt of the Wawa Subprovince in the last few years has resulted in the continued and increasing interest in diamond exploration in the Wawa area. To date, all significant discoveries of diamonds in Archean rocks are located within a block encompassing the townships of Lalibert, Menzies, Leclaire and Musquash (Figure 9.1).

A large portion of the Michipicoten greenstone belt was the target of extensive and detailed bedrock mapping (1:15 840 scale) and investigation between 1979 and 1994 by R.P. Sage (Sage 1993a, 1993b, 1993c, 1993d, 1994) from the Ontario Geological Survey (OGS).

The investigation of Menzies Township with geological bedrock mapping at a scale of 1:20 000 was undertaken this summer principally because it is the only one of the four townships where diamond-bearing rocks were found that was not included in the previously listed studies. This township has actually never been part of any detailed studies by the OGS. The continuation of this project is not yet clearly defined and will be determined on an ongoing basis to best suit the evolution of our understanding of the area and the needs of the exploration industry.

REGIONAL GEOLOGY

Three cycles of supracrustal rocks were defined in the Michipicoten greenstone belt (Turek, Sage and Van Schmus 1992; Sage 1994, and references cited therein). The oldest cycle (cycle 1, circa 2900 Ma: Turek, Smith and Van Schmus 1984) is composed of ultramafic and tholeiitic mafic metavolcanic rocks at the base. These are overlain by intermediate to felsic calc-alkalic metavolcanic rocks, mostly composed of tuffs and breccias. This is capped by minor iron formation (including the Judith Iron Range and possibly the Holdsworth Iron Range). The two following cycles (cycles 2 and 3) (circa 2750 Ma: Turek, Smith and Van Schmus (1982, 1984); and 2700 Ma: Turek, Sage and Van Schmus (1992), respectively) are generally defined by the same sequence of rocks as cycle 1 (2900 Ma), but do not have ultramafic rocks at their base. The iron formation that caps cycle 2 is host to all the iron mines in the Michipicoten greenstone belt. The Doré metasediments are interpreted to be contemporaneous with the last cycle as they overlie and are interlayered with intermediate to felsic metavolcanic rocks of this cycle (Sage 1994). The Doré conglomerate is characterized by units containing large granitic boulders.

Summary of Field Work and Other Activities 2003, Ontario Geological Survey, Open File Report 6120, p.9-1 to 9-11.

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Intermediate to mafic intrusive rocks ranging from gabbro to quartz-diorite are commonly found throughout the stratigraphy and ultramafic intrusions are present, but scarce (Sage 1993a, 1993b, 1993c, 1993d). Numerous intermediate to felsic intrusive rocks were emplaced into the volcanic rocks. Geochronological studies revealed intrusive rocks that are synchronous with all 3 cycles of volcanism. However, some ages obtained on intrusive rocks have no known extrusive equivalents. These include trondhjemite-tonalite, granodiorite and quartz-monzonite, and syenitic stocks (Sage 1994).

Archean lamprophyres have only been found between the Magpie iron mine and the eastern contact of the Dickenson Lake stock in Lalibert Township (Sage 1993b, 1993d). Geochronological studies revealed a maximum age of approximately 2685 Ma for the emplacement of at least some of the Archean lamprophyres (Stott et al. 2002; Ayer, Conceição et al., this volume). Proterozoic lamprophyres interpreted by Sage (1993a) to be related to alkalic magma emplacement into the Kapuskasing Structural Zone are spatially restricted to an area south of the Wawa Lake–Manitowik Lake fault system.

Late Archean and Proterozoic diabase dikes are found throughout the greenstone belt. They are generally fresh and undeformed, although some quartz veining accompanied by week epidote, carbonate and chlorite alteration is found locally. The diabase dikes dominantly strike northwest and northeast.

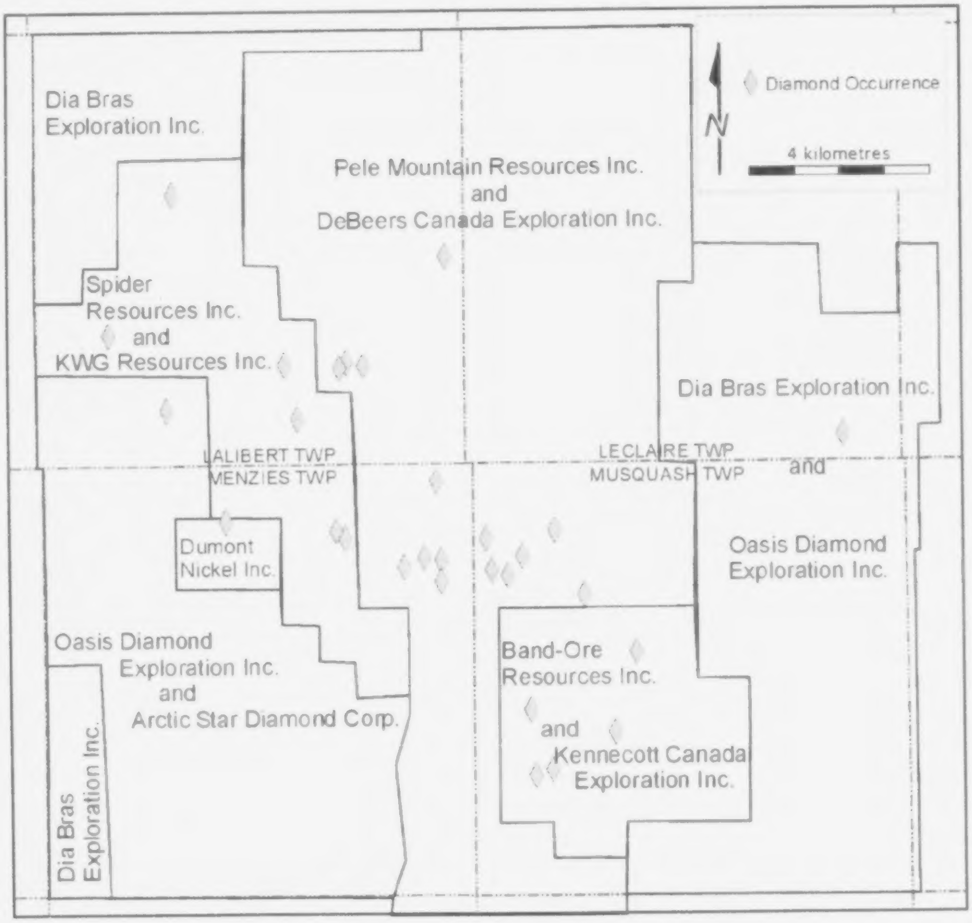
Diamond Occurrence
N
4 kilometres
Dia Bras Exploration Inc.
Pele Mountain Resources Inc. and DeBeers Canada Exploration Inc.
Spider Resources Inc. and KWG Resources Inc.
Dia Bras Exploration Inc. and Oasis Diamond Exploration Inc.
LALIBERT TWP
MENZIES TWP
LECLAIRE TWP
MUSQUASH TWP
Dumont Nickel Inc.
Oasis Diamond Exploration Inc. and Arctic Star Diamond Corp.
Band-Ore Resources Inc. and Kennecott Canada Exploration Inc.
Dia Bras Exploration Inc.

Figure 9.1. Location of mining properties and diamond occurrences for Menzies, Lalibert, Leclaire and Musquash townships (*modified from* Atkinson et al. 2003).

MAP AREA

Menzies Township is underlain by rocks that belong to the volcanic cycle 2 in the southwest and to the volcanic cycle 3 in the northeast. A dioritic intrusion breccia and massive granodiorite underlie the southwest and southern portions of the township, respectively (Figure 9.2).

Mafic and felsic metavolcanic rocks, and iron formations interpreted to belong to volcanic cycle 2 (2750 Ma) are found in the southwest portion of the map area. Felsic metavolcanic rocks were sampled for a geochronological study with the aim of confirming or disproving this interpretation. The results are expected to be published in *Summary of Field Work and Other Activities 2004*.

Mafic, mostly pillowed flows, mafic to intermediate massive flows and breccias, and a large variety of felsic and intermediate tuffs, crystal tuff and tuff breccias overlie the iron formation of the volcanic cycle 2 to form what is interpreted to be the volcanic cycle 3 in the map area. An age of 2701.4±2.1 Ma obtained on an intermediate tuff by Ayer, Conceição et al. (this volume) supports this interpretation.

The mafic and felsic metavolcanic rocks are generally similar in both volcanic cycles. Rocks from the volcanic cycle 2 are more deformed near the contact with the intrusion breccia interpreted to be a border facies to the large diorite-granodiorite body to the southwest of the township.

Mafic and Ultramafic Metavolcanic Rocks

Mafic metavolcanic rocks of both cycles are mainly pillowed flows with minor massive flows and breccias. In both cycles, the flows have locally undergone intense alteration followed by metamorphism, which resulted in the crystallization of very large amphiboles and carbonates. The primary volcanic textures are surprisingly well preserved, given that some amphibole crystals have lengths over 3 cm.

Heterolithic breccias that host major diamond occurrences are typically found above pillowed and massive mafic metavolcanic flows of the volcanic cycle 3. These breccias contain a wide variety of fragments including felsic and mafic volcanic rocks, ultramafic rocks and occasional cherty magnetic fragments possibly derived from an iron formation. The matrix is mostly ultramafic in composition. Podiform masses occur where the breccia matrix is replaced by a darker intrusive-looking phase, which was observed at many of the known diamond occurrences (Photo 9.1). These are tentatively interpreted to represent infiltration of lamprophyric magma in the unconsolidated breccia. More detailed work is going to be undertaken to better understand these features and to determine if they could have a relationship with the presence of diamonds in the breccia. The apparent repetition of the heterolithic breccia is currently interpreted to be the result of folding and/or thrusting. Detailed mapping, and a thorough study of structural deformation in the northeast corner of Menzies Township, and the eastern portion of Musquash Township is required to verify and clarify this hypothesis.

Felsic to Intermediate Metavolcanic Rocks

Plagioclase and quartz-plagioclase crystal tuffs are the most abundant components of the felsic to intermediate metavolcanic rocks. There is a range of compositions between the two end members. Mafic minerals (biotite and/or chlorite and/or amphiboles) are less abundant in the quartz-rich portions of the sequence. These tuffs are generally very massive, which makes it difficult to distinguish extrusive from intrusive phases. The presence of local graded bedding, finely laminated tuffaceous intersections, and lapilli-tuff and tuff breccia horizons are the only rare tools to clearly identify extrusive phases. At this time, heterolithic breccias composed of a majority of felsic fragments in a compositionally varied matrix are included in the felsic metavolcanic portion of the cycle 3 volcanic rocks, pending more information from ongoing studies, including geochemistry and petrography. These breccias appear as sediments on previously published large-scale maps (Goodwin 1963; Milne et al. 1972; Santaguida 2001).

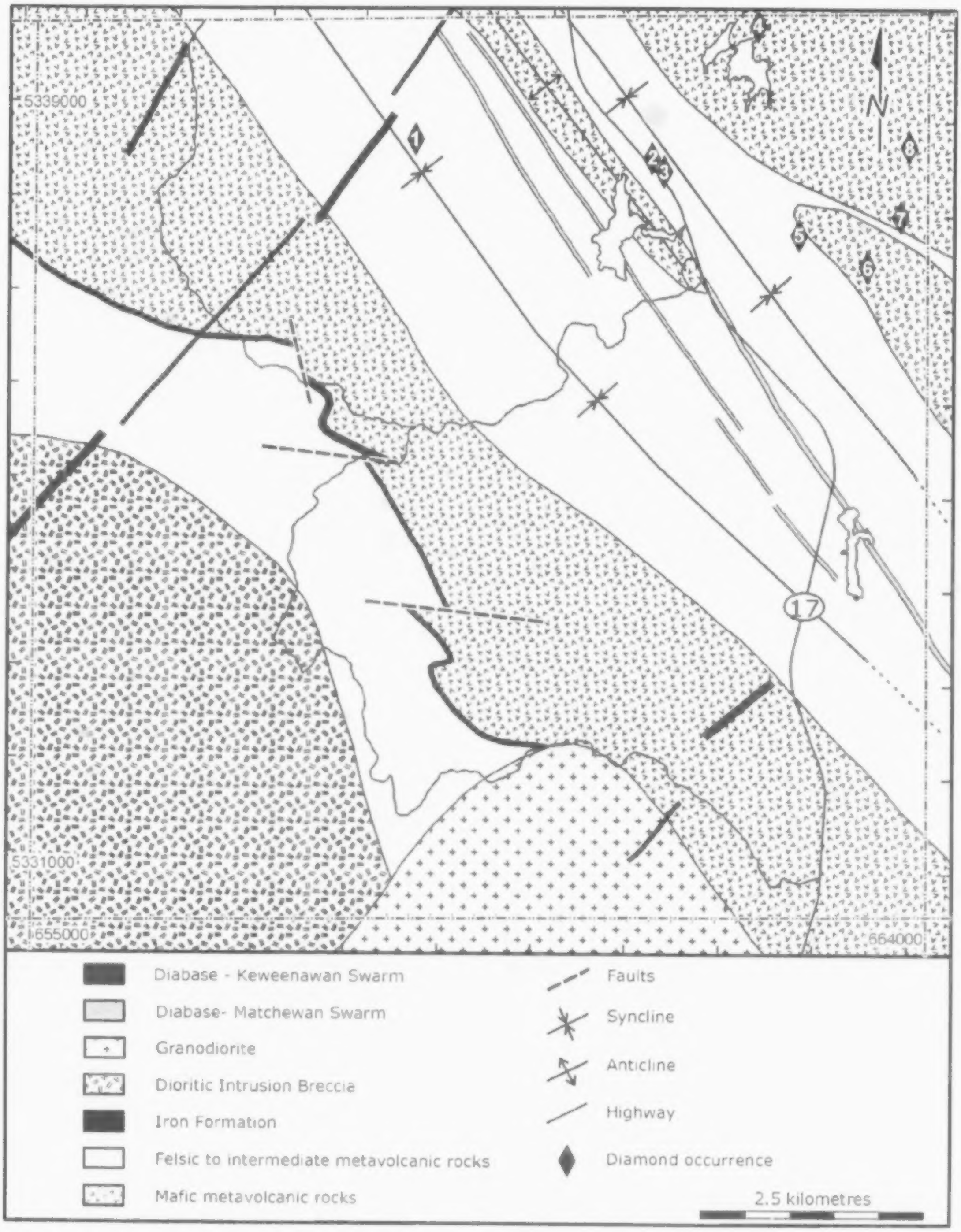
5339000
5331000
655000
664000
N
17
1
2
3
4
5
6
7
8
Diabase - Keweenawan Swarm
Diabase- Matchewan Swarm
Granodiorite
Dioritic Intrusion Breccia
Iron Formation
Felsic to intermediate metavolcanic rocks
Mafic metavolcanic rocks
Faults
Syncline
Anticline
Highway
Diamond occurrence
2.5 kilometres

Figure 9.2. General geology of Menzies Township. Diamond occurrences are 1 - Dumont Sample 4073 (Dumont Nickel Inc.); 2 - MEN-107, 3 - MEN-106 (Spider Resources Inc., KWG Resources Inc., Diagem International Resources Corp.); 4 - Veuve Cliquot, 5 - Moet, 6 - Mumm, 7 - Genesis, 8 - Rossignol (Pele Mountain Resources Inc., DeBeers Canada Exploration Inc.).

Iron Formation

The expression on the magnetic and electromagnetic airborne geophysical surveys (Ontario Geological Survey 1999, 2003) of the iron formation at the top of volcanic cycle 2 is a very good marker horizon. This iron formation may be very wide in other parts of the belt, but appears to be fairly narrow in the map area and only a few outcrops were observed. It is mainly composed of banded chert and magnetite horizons, but sulphide-rich horizons were also observed. It is generally northwest striking and its very shallow dip makes outcrop location and map patterns highly dependent on topography.

Mafic and Ultramafic Intrusive Rocks

A variety of leuco- to melagabbros and amphibolites are found principally as large fragments in the heterolithic intrusion breccia described in the following section. These rocks may be genetically related to the dioritic intrusion located southwest and west of Menzies Township. Some mafic dikes are also found in the felsic metavolcanic rocks of cycle 2, near the intrusion breccia.

Synvolcanic gabbro dikes are found within the mafic metavolcanic portions of cycle 3. Unless clearly extrusive texture like pillows selvages and flow-top breccias are present, it is locally impossible to distinguish extrusive from intrusive mafic rocks because of the intense metamorphic recrystallization.

Lamprophyric dikes of slightly variable compositions were only found in the north and northeast portions of the map area. The matrix is composed of biotite and/or chlorite and may contain amphiboles. The lamprophyric dikes host a variety of locally derived fragments of felsic and mafic volcanic and

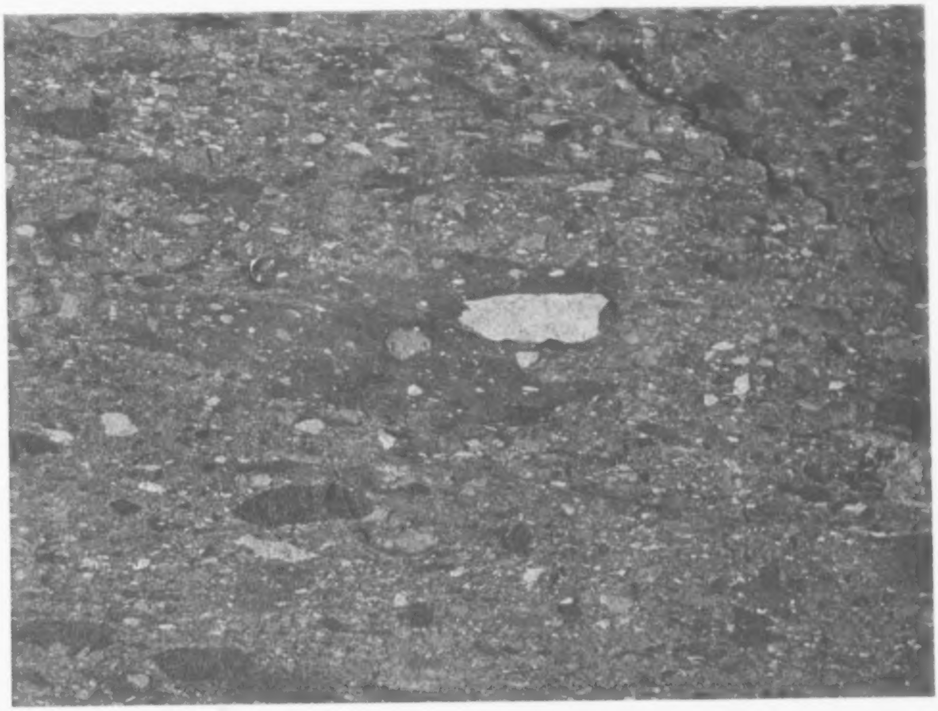

Photo 9.1. Diamond-bearing heterolithic breccia with a dark podiform mass replacing the matrix.

intrusive rocks, and also a significant proportion of actinolite, talc and carbonate fragments of uncertain origin. These fragments are systematically surrounded by a dark reaction rim (Photo 9.2). The lamprophyric dikes display very different intensities of deformation, which could indicate that there is more than one lamprophyric intrusion event. However, it is als[illegible]ble that the difference is simply due to proximity to high-strain zones.

Diamonds were recovered from a number of these dikes by exploration companies (*see* "Exploration History and Update"). Some workers believe that the lamprophyric dikes are not diamond-bearing and that the diamond was assimilated into the dikes when they intruded the diamond-bearing heterolithic breccia. This hypothesis can be tested by analyzing for diamonds in lamprophyre dikes that intrude metavolcanic rocks situated below the stratigraphic level of the heterolithic breccias (i.e., within the pillowed flows of volcanic cycle 3 or lower). Also, diamond analysis of small samples of carefully selected material from the breccias (matrix and specific xenoliths) could help in the determination of the actual location of the diamonds within the very heterolithic material. These studies are part of the plan for future work in the area.

Felsic to Intermediate Intrusive Rocks

The southwest corner of Menzies Township is underlain by a complex heterolithic intrusion breccia that is interpreted to represent the border facies of a felsic to intermediate intrusion located west and south of the map area. Because of the generally shallow-dipping stratigraphy, the border facies appears to be very wide on the map, but its true thickness is likely much narrower. Because of the shallow-dipping contact, and the fact that the border facies contains large inclusions of the host felsic metavolcanic rocks,

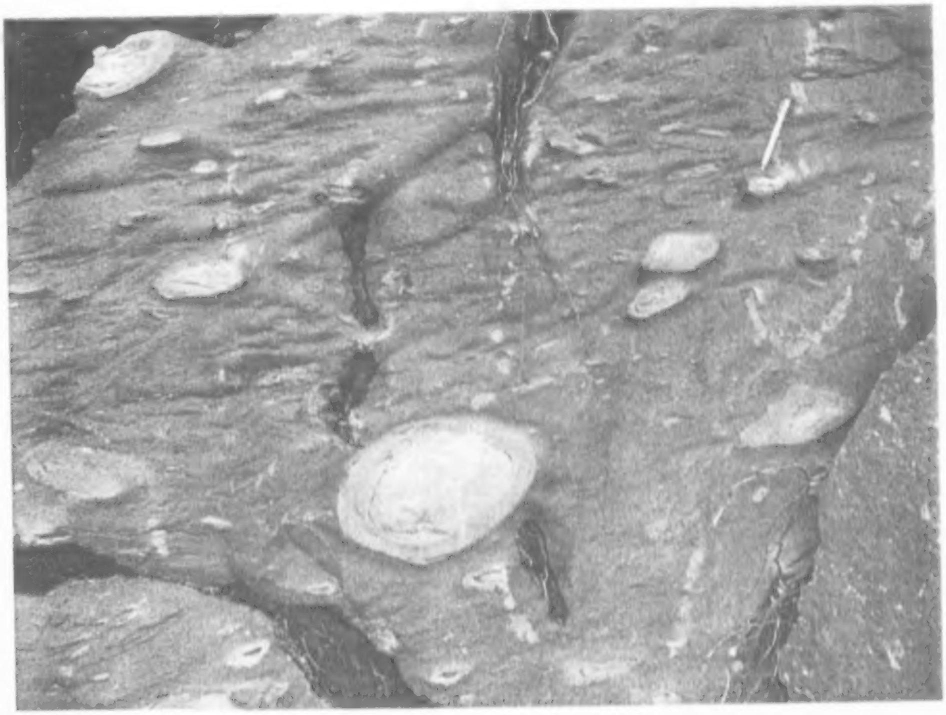

Photo 9.2. Diamond-bearing lamprophyre. Fragments have a well-developed dark reaction rim.

it is difficult to draw an actual contact for the intrusion. More work will be required in this portion of the township since time constraints did not allow for mapping in this area during 2003. It is hoped that more targeted work can be carried out next summer after all the data collected in 2003 is compiled and evaluated.

The heterolithic breccia contains a variety of mela- to leucogabbro enclaves, and gneissic mega-fragments. The mafic to intermediate enclaves are currently interpreted to be cognate to the diorite that is the matrix to the intrusion breccia. Further petrographic and geochemical work will help interpret genetic relationships in more detail. The gneissic fragments could either be xenoliths of older rocks or simply early phases of the pluton that were deformed into gneiss during emplacement. A multitude of dikes with compositions ranging from leucogabbroic to quartz-dioritic are found throughout the border zone. It appears that the more felsic lithologies intrude the more mafic rocks, but this interpretation is based only on very few and local observations.

A very massive and homogeneous granodiorite body is present in the central portion of the southern boundary of Menzies Township. Although no contact was directly observed, this body appears to be in direct and sharp contact with the mafic metavolcanic rocks at the base of cycle 3 (2700 Ma) because no border facies was observed in this area.

Diabase Dikes

The northwest-striking diabase dikes in the map area are interpreted to be part of the Matachewan and Hearst swarms, but petrographic and geochemical work will be required to confirm this interpretation. A big northeast-striking dike intrudes the rocks in the northwest corner of the map area. An age of 1142±3 Ma (L.M. Heaman, unpublished data cited in Sage 2000, p.7) was obtained on this dike, which indicates that it is part of the Keweenawan diabase swarm.

Structure

Two main deformation events were recognized. The first and most intense episode is manifested through folds with northwest, shallow-dipping axial surfaces, and northeast-plunging axes. This orientation is generally subparallel to stratigraphy and may be equivalent to D_2 described by Arias and Helmstaedt (1990) east of the map area. Large-scale folds of this orientation are responsible for the stratigraphic repetition of cycle 3 metavolcanic rocks and the overturned facing direction in the northeast corner of the map area. An intense penetrative foliation and localized shear zones are associated with the folds. Low-amplitude folds with a subvertical axial plane and northeast-plunging axes overprint the previously described deformation event. Foliation related to this deformation is typically weak to absent. This may be equivalent to D_3 described by Arias and Helmstaedt (1990).

The structural history of the area is likely more complex and involves more than 2 episodes of deformation. The 2 episodes described here are those that are best developed and recognizable at a scale of 1: 20 000 in Menzies Township. Substantially more work will be required to fully understand the effects of each event and how they fit in the regional tectonic history. It is hoped that at least some questions will be answered through the study of the data that were collected this summer, and that more oriented work can be carried out in the coming years.

Metamorphism

Most of the map area has undergone greenschist-facies regional metamorphism. Some areas are believed to have undergone amphibolite-facies metamorphism, possibly related to the emplacement of large granitic batholiths to the south and west. Thorough petrographic study will be required to better understand the distribution and effect of the intrusions and other subtle variations in the metamorphism in the map area.

RECOMMENDATIONS FOR EXPLORATION

The large intrusion found in the southwestern corner of Menzies Township and covering a large part of Macaskill Township is poorly understood and has never been mapped. It appears to be more complex than a simple granodiorite body as portrayed on the large-scale map of the area and may warrant more attention. For example, the presence of large mafic and ultramafic fragments may indicate the presence of a nearby mafic–ultramafic intrusion[1], which could have potential for platinum group element (PGE) mineralization.

From what is currently known, both the mafic to ultramafic heterolithic breccia of volcanic cycle 3 and the lamprophyric rocks located near the breccias represent good targets for diamond exploration. Because these rocks are heterogeneous and largely contain locally derived components, it is difficult to set criteria for the determination of the diamond-bearing potential of a breccia or a lamprophyre dike. At this point, there are many theories to be tested before statements can be made. Such work will be carried out in the coming years, as the definition of this project evolves with our understanding of the nature and deformation of the diamond-bearing rocks, the origin of the diamonds, and their actual location within their host rocks.

EXPLORATION HISTORY AND UPDATES

Arctic Star Diamond Corp. and Oasis Diamond Exploration Inc. – Enigma Project

The Enigma project is a 68 614 km^2 mining property that encompasses the western two-thirds of Menzies Township and a portion of the southwest corner of Lalibert Township. Oasis Diamond Exploration Inc. holds 2 separate mineral exploration licenses on the property. Since early 2002, exploration on the property is conducted as a joint venture partnership between Oasis Diamond Exploration Inc. and Arctic Star Diamond Corp.

In the fall of 2001, Oasis Diamond Exploration Inc. conducted a regional reconnaissance-scale exploration program over the entire property. The program consisted of stream sediment sampling (34 samples), trenching and the collection of approximately 300 kg of diamondiferous bedrock, mostly from what is now called the "Enigma Zone", located in southwest Lalibert Township. A total of 209 diamonds, including 2 macro-diamonds, were recovered from 189 kg of bedrock.

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[1] As used in this article, the term "mafic–ultramafic" refers to intrusions composed of mafic rocks only, ultramafic rocks only, or a combination of mafic and ultramafic rocks.

A second diamondiferous occurrence called the Sigma zone and located in central Menzies Township was discovered during this exploration program. Three rock samples and 6 stream sediment samples were collected. Twenty-one micro-diamonds were recovered from a boulder sample.

In order to more fully evaluate the size and shape of the 700 m long Enigma zone, a ground geophysical survey and a seven-hole diamond-drill program were completed in the winter of 2001–2002. Eight micro-diamonds were recovered from 485.44 kg of drill core. A follow-up detailed sampling and mapping program is planned for the fall of 2003 (Arctic Star Diamond Corp., Iciena Ventures Inc. and Oasis Diamond Exploration Inc., press releases, April 23, July 15 and November 20, 2002; Arctic Star Diamond Corp., press release, September 15, 2003; Marchand 2002).

Dia Bras Exploration Inc. – Macaskill Property

Dia Bras Exploration Inc. and Oasis Diamond Exploration Inc. signed a joint venture agreement on the 80.63 km^2 Macaskill property in the fall of 2002. The property lies to the west and north of Oasis Enigma project and includes the northeast corner of Macaskill Township and the southeast corner of Menzies Township, as well as portions of Knicely and Lalibert townships. During the summer of 2003, Dia Bras Exploration Inc. conducted a reconnaissance-scale prospecting and geological mapping program on the property. Stream sediment samples (25 total) and bedrock samples were collected and will be analyzed for kimberlite indicator minerals and diamond content (Dia Bras Exploration Inc., press releases, July 14 and August 13, 2003). To date, there are no confirmed mineral occurrences on the Macaskill property.

Dumont Nickel Inc. – Wawa Diamond Property

In 2000, Dumont Nickel Inc. acquired the mineral rights to a 77 km^2 property in Knicely and Menzies townships. The Menzies Township property is approximately 2 km^2 and located in the centre of the township. During the 2000 field season, Dumont Nickel Inc. conducted a reconnaissance program of focussed lamprophyre sampling and analysis. A 49.2 kg sample of lamprophyric bedrock returned 12 micro-diamonds. No additional exploration work was reported by the company (Dumont Nickel Inc., press release, August 21, 2000).

Pele Mountain Resources Inc. – Festival Diamond Property

Pele Mountain Resources Inc. acquired the mining rights to the 101 km^2 Festival property in early 2000. The property encompasses ground in Lalibert and Leclaire townships and along the east side of Menzies Township.

Over the 2000–2002 field seasons, Pele Mountain Resources Inc. conducted a prospecting, mapping, outcrop stripping, trenching and sampling program along the southern margin of the Festival property, including an area in the northeast corner of Menzies Township. This exploration program resulted in the discovery of 6 bedrock-hosted diamond occurrences. These occurrences include B-1, Moet, Veuve Cliquot, Mumm, Genesis and Genesis West. A 17 kg grab sample taken from the Genesis occurrence returned 308 diamonds with 120 diamonds remaining on the +106 micron sieve. A 4500 kg bulk sample taken from the Genesis occurrence in 2002, returned 53 commercial-size diamonds down to a bottom screen size of 0.8 mm. The total weight of the recovered diamonds was 0.52 carats (Pele Mountain Resources Inc., press releases, July 26, 2001, and September 12, 2002).

In 2003, Pele Mountain Resources Inc. continued an exploration program of detailed mapping and sampling of the diamond occurrences in the southwest corner of the Festival property, including those in Menzies Township. In July 2003, Pele Mountain announced that they have entered into a joint venture and option agreement with DeBeers Canada Exploration Inc. on the Festival property. Exploration work on the property by DeBeers Canada Exploration Inc. during the 2003 field season was planned to include a minimum 300 tonnes of bulk sampling (Pele Mountain Resources Inc., press release, July 31, 2003).

Spider Resources Inc. and KWG Resources Inc. – Spider Project

Spider Resources Inc. with joint venture partners KWG Resources Inc. and Diagem International Resource Corp. hold the mineral rights to a 45 km^2 property straddling Highway 17 in Menzies and Lalibert townships. This property was first acquired in 1996 following the discovery of the Sandor diamond occurrence in Lalibert Township.

In 1996 and 1997, Spider Resources Inc. completed an exploration program of regional till sampling, bedrock sampling of mafic dikes, bulk sampling of known diamond occurrences, trenching of mafic dikes and detailed geological mapping in areas of known mafic dikes over the entire property. Two diamond occurrences were discovered during this exploration program. The first occurrence (dike 107, sample 96MEN-107) returned 6 micro-diamonds, 1 macro-diamond and 1 commercial diamond from a 28.3 kg sample taken along side Highway 17. A second sample (164.7 kg) from this outcrop returned 81 micro-diamonds, 11 macro-diamonds and 3 commercial diamonds. A 27.6 kg sample from a dike (96MEN-106) at the second occurrence returned 1 micro-diamond and 1 macro-diamond. No additional work is reported at these 2 occurrences.

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10. Project Unit 03-012. The Timing and Petrogenesis of Diamondiferous Lamprophyres in the Michipicoten and Abitibi Greenstone Belts

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INTRODUCTION

This report provides an update on the age and geochemistry of the diamondiferous lamprophyres in the Michipicoten greenstone belt (MGB) and the Abitibi greenstone belt (AGB) in an effort to better understand their petrogenesis and to provide new exploration criteria. Diamonds have recently been discovered in Archean lamprophyres and associated heterolithic breccias in 2 localities in the Superior Province: within the Michipicoten greenstone belt in the Wawa area, and within the Abitibi greenstone belt in the Cobalt area. An age of 2674±8 Ma for titanite in a lamprophyre dike was obtained from a sample collected by R.P. Sage, Ontario Geological Survey, from the GQ discovery site held by Band-Ore Resources Limited in Musquash Township (Stott et al. 2002). This is similar to the age reported for titanite from a non-diamondiferous lamprophyre dike in the Kirkland Lake area (Wyman and Kerrich 1993). Thus, these lamprophyres are some of the oldest known primary host rock sources of diamonds and represent the first confirmed occurrence in calc-alkaline lamprophyres. The presence of Archean diamonds in these rocks is problematic in that their chemistry indicates derivation by partial melting of spinel lherzolitic mantle at depths of less than 80 km, whereas diamonds are typically derived from sources at depths greater than 150 km.

LAMPROPHYRE PETROGENESIS

Archean lamprophyres are a common, but volumetrically minor, rock type in the Superior Province. The dikes display a preferred association with major crustal structures. Field relations consistently indicate a late to postkinematic timing for lamprophyre dike emplacement and a common association with other Neoarchean alkalic rock types. The dikes are among the youngest members of the alkalic suite in a given area. The late to postkinematic emplacement of lamprophyres and associated rock types indicates that the origin of the alkalic suite was specifically related to late-tectonic accretion of subprovinces of the Superior Province into an amalgamated craton. A wide range of petrographic and mineralogical features indicates that crystal fractionation generally occurred in conjunction with the mixing of variably evolved batches of lamprophyric magma.

Summary of Field Work and Other Activities 2003, Ontario Geological Survey, Open File Report 6120, p.10-1 to 10-9.

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Major element compositions of the Archean lamprophyres confirm the similarity of the older dikes with younger dikes of shoshonitic affinity. Weakly altered dikes typically have contents of SiO_2 (47 to 51 weight %), TiO_2 (0.5 to 1.4 weight %), and P_2O_5 (0.36 to 1.58 weight %) and K_2O/Na_2O ratios (0.36 to 1.58) similar to Phanerozoic lamprophyres. Weakly altered dikes are also characterized by extreme enrichments of the large ion lithophile elements (LILE) K, Rb, Ba, Cs, Th, U, and light rare earth elements (LREE) and, in primitive lamprophyres, enhanced abundance of Cr (650 to 960 ppm), Co (37 to 42 ppm), Ni (264 to 358 ppm) and Sc (22 to 33 ppm). The major and trace element abundance of weakly altered dikes collectively indicate that the lamprophyres were derived from a depleted mantle source, variably enriched in LILE and LREE.

The oxygen isotope ($\delta^{18}O$) composition of the Abitibi lamprophyre magma was close to the 6.3 per mil (‰) value obtained from a clinopyroxene mineral separate (Wyman and Kerrich 1993). This value is comparable to that of Colima Graben minette clinopyroxenes (Kyser, O'Neil and Carmichael 1981) and provides further evidence that Archean and Phanerozoic shoshonitic lamprophyres were derived from similar mantle sources.

Samarium-neodymium isotopic compositions of lamprophyres from the Superior Province are comparable to those of other members of the late alkalic suite (ε_{Nd}= ~0.5 to ~2.0). Lamprophyre compositions in the Abitibi Subprovince, for example, encompass slightly lower ε_{Nd} values than pre-kinematic mantle-derived rock types of the same region. Collectively, the Sm-Nd compositions of alkalic rock types in the Superior Province may be explained by enrichment events that incorporated old crustal material or fluids derived from such material. The relatively high $\delta^{18}O$ values of Archean lamprophyres are consistent with a clastic sedimentary component in their mantle source.

Recent research has shown that the diamond-bearing lamprophyres tend to be geochemically more primitive than the non-diamond-bearing lamprophyres from the Superior Province and define distinct chemical trends that only partially overlap trends for other Archean lamprophyres (Figure 10.1; Williams 2002). This characteristic is a consequence of contamination of the diamondiferous lamprophyre parent magmas with a primitive material compositionally similar to komatiite, which may have been diamond bearing. The compositions of ultramafic xenoliths found in some diamond-bearing dikes indicate that these inclusions are probably not the komatiitic contaminant.

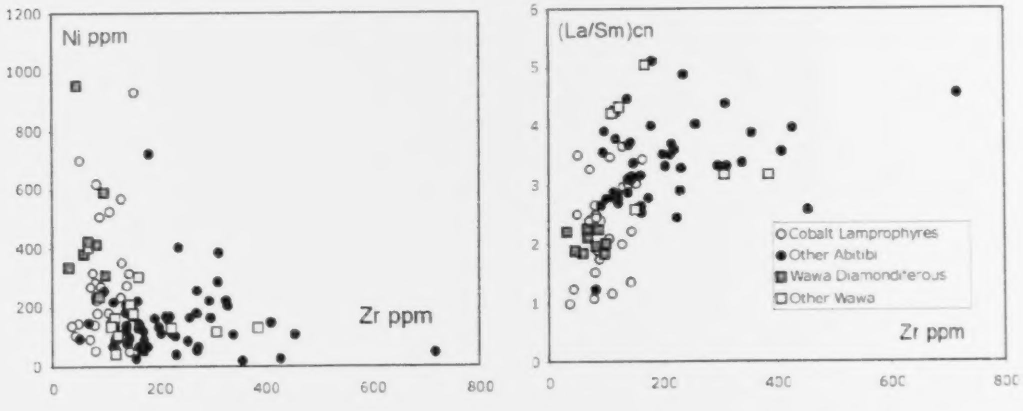

Figure 10.1. Trace element plots for diamondiferous (open circles and filled squares) and non-diamondiferous (filled circles and open squares) lamprophyres of the Abitibi and Wawa subprovinces (Williams 2002). Diamondiferous lamprophyres extend to more primitive and incompatible element-enriched compositions with less fractionation of the light rare earth elements. However, individual diamond-bearing samples occur in the region of overlap on these plots. Abbreviation: cn, chondrite normalized.

ARCHEAN LAMPROPHYRE-ASSOCIATED DIAMONDS

Diamonds have been recovered from hypabyssal dikes and heterolithic breccias from 2 districts in the Wawa and Abitibi subprovinces (Stott et al. 2002). Diamond-associated lamprophyre dikes in the Michipicoten greenstone belt are distinguished from other Archean lamprophyres by the presence of rounded to subangular ultramafic xenoliths that are up to 1 m in diameter (Sage 2000). More than 20 000 diamonds have been recovered from the dikes and associated breccias, with over 95% being microdiamonds. The diamonds are clear, white, yellow, pink and green and occur as fragments, octahedroids and twinned polytetrahedroids (Sage 2000). Grade estimates range from 0.2 to 1 carat per tonne with the largest stone recovered to date being in excess of 0.7 carat.

Secondary electron (SE) micrographs were made of diamonds from the Lorrain Township (Abitibi greenstone belt) (provided by Cabo Mining Corp.) and the Musquash Township (Michipicoten greenstone belt) heterolithic breccia occurrences. Micrographs taken by the Geoscience Laboratories, Geoservices Centre, Sudbury, show that the macrodiamonds from the Lorrain Township occurrence have eroded surfaces and apices (Photo 10.1A) and the microdiamond fragments have corroded and embayed surface textures (Photo 10.1B), both of which indicate strong resorption before or during emplacement. The diamonds from Lorrain Township also exhibit a cascading charging pattern under a secondary electron beam that has not been previously observed in diamonds from other localities. These textures are distinct from the diamond micrographs from the Musquash Township occurrence, which show the typically smooth and clear surfaces observed in the Wawa diamonds (Photos 10.1C and 10.1D).

NEW ISOTOPIC DATA

Uranium-Lead Geochronology

Geochronological (U/Pb) analyses were conducted at the Jack Satterly Geochronology Laboratory, Royal Ontario Museum and involved standard rock crushing, mineral separation, zircon and titanite selection, dissolution, and thermal ionization mass spectrometry techniques. Zircons were air abraded to reduce discordance and were analyzed without chemical isolation of uranium and lead due to their small size (almost all <3 μg). The vast majority of analyses represent single zircon crystals. Age uncertainties cited in the text and shown in concordia plots are given at the 95% confidence level.

SAMPLE A

Sample A, from a volcanic unit hosting diamondiferous lamprophyre dikes and heterolithic breccias, was sampled (02JAA-0016) for geochronology on the Enigma property held by Oasis Diamond Exploration Limited, in Lalibert Township (UTM: Zone 16, 657153E, 5340010N). The volcanic rocks are calc-alkaline dacite and contain medium-grained plagioclase phenocrysts in a fine-grained, recrystallized matrix of feldspar, quartz, biotite and amphibole. Elsewhere in the outcrop, lapilli tuff consist of heterolithic mafic to felsic fragments up to 30 cm long in a matrix of the same composition as the tuffs. A lamprophyre dike with rounded, talcose ultramafic xenoliths crosscuts the intermediate volcanic rocks.

The zircon population is mixed, consisting mainly of small subhedral and anhedral grains of poor to good quality. Larger, poor-quality, equant to 3:1 (length: width) grains are also present, and some of these may contain inherited cores. Colourless subhedral prisms with and without cracks and fluid inclusions were abraded in 2 groups: long prisms (>4:1) and equant to 2:1 prisms. Four analyses of this material, which is representative of the main zircon population, provide an average ^{207}Pb/^{206}Pb age of 2701.4±2.1 Ma (10% probability of fit (p.o.f.)[1], MSWD[2] = 2.1) (Figure 10.2A), which is interpreted to represent the primary age of the unit. This age is consistent with the reported age for Michipicoten greenstone belt cycle 3 volcanism (Turek, Sage and Van Schmus 1992).

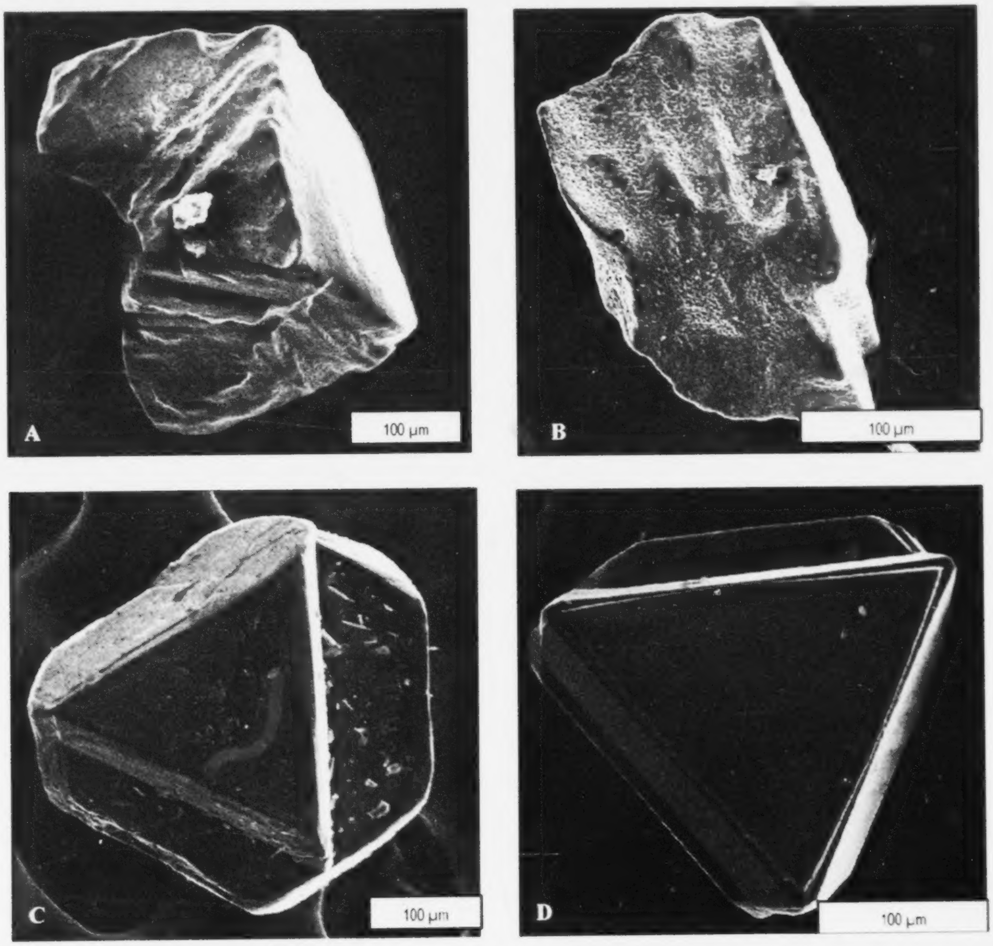

Photo 10.1. Secondary electron (SE) micrographs of diamonds from Lorrain Township showing pumice-like surface texture (A and B) and from Wawa (C and D) with flat uneroded surfaces and sharp apices. Figure 10.1C processed by disk mill, magnetic separation and heavy liquid separation. Figure 10.1D processed by caustic dissolution. All SE micrographs collected on a JEOL 6400 scanning electron microscope (SEM) using a beam current 0.07 nA. Figures 10.1A and 10.1B collected using 10 keV accelerating voltage (due to excessive charging); Figures 10.1C and 10.1D collected using 20 keV accelerating voltage.

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[1] probability of fit: Indicates the probability that the scatter of analyses about a Pb-loss line is due to analytical uncertainty alone. A value of about 50% is expected for a unimodal population. A value significantly less suggests differences in zircon age and/or Pb-loss history.

[2] mean square of weighted deviates: Also evaluates goodness of fit. MSWD = 1 to 2.5 indicates acceptable fit, >2.5 indicates more scatter than is expected from analytical uncertainty alone.

SAMPLE B

A brown-weathering, biotite-rich lamprophyre dike several metres wide is hosted by homogeneous metagabbro and intermediate composition amygdaloidal flows on the Enigma property held by Oasis Diamond Exploration Limited, in Lalibert Township (UTM: Zone 16, 656022E, 5340393N). The dike contains euhedral carbonate porphyroblasts and numerous gneissic and ultramafic xenoliths. A sample of the dike (02JAA-0015) was collected from a carbonate-rich, enclave-free area. A thin section of this sample contains possible relict olivine within a large clot of biotite and opaque minerals.

A variety of zircon types were recovered, suggesting a dominantly xenocrystic population. The largest grains are colourless to light pink and light brown, resorbed, and generally cracked, but otherwise of excellent quality. Smaller grains are mainly colourless, equant and 2:1, subhedral and anhedral resorbed prisms. Many zircons are brittle, possibly due to pressure release-related microfracturing during dike emplacement.

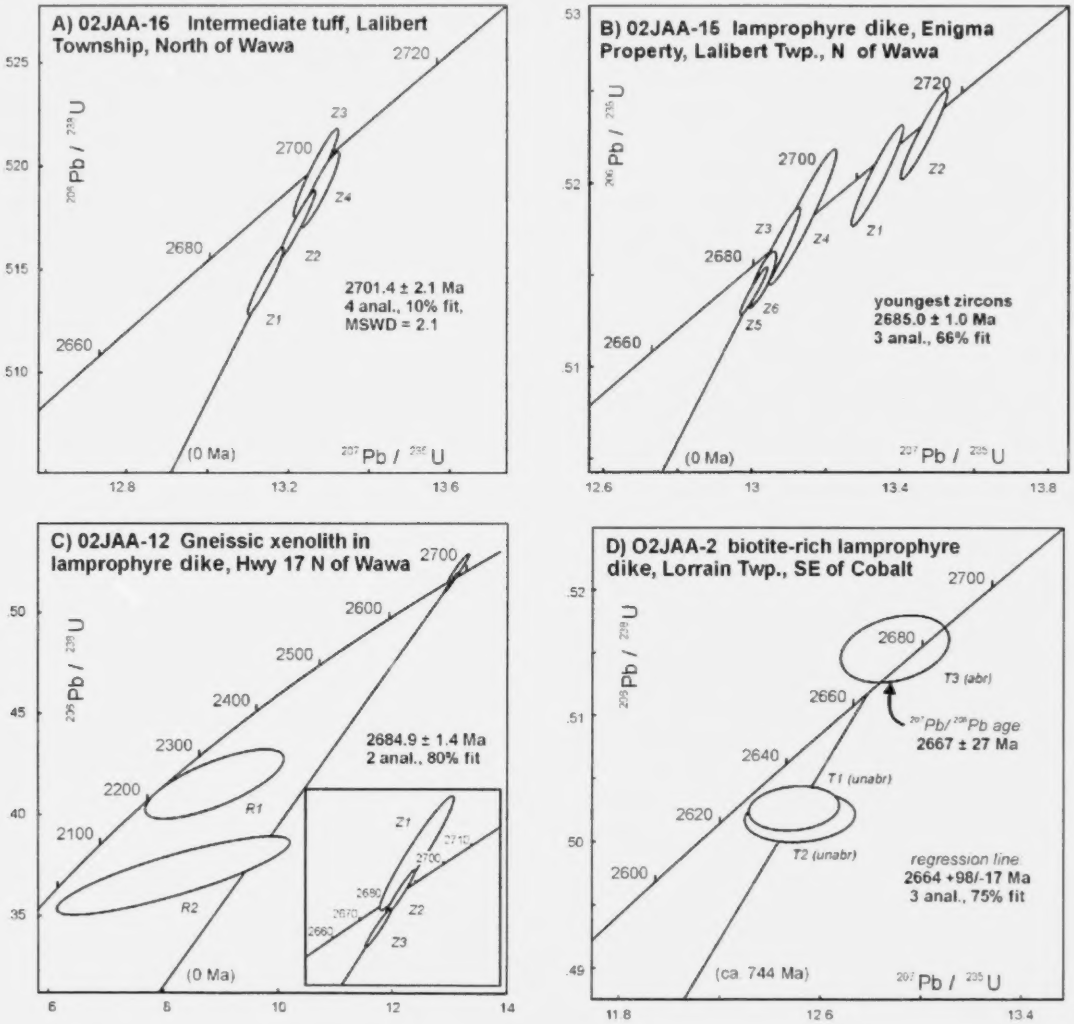

Figure 10.2. Concordia diagrams with U/Pb analyses for zircon and rutile. Ellipses indicate the 2σ uncertainty.

Six fractions were analyzed. The 3 youngest overlap within uncertainty with an average ^{207}Pb/^{206}Pb age of 2685.0±1.0 Ma (66% p.o.f.) (Figure 10.2B). These grains are colourless to brown and have a wide range in Th/U (0.05 to 1.7). Older concordant ages of 2689 Ma, 2706 Ma and 2715 Ma were obtained from mainly smaller colourless grains. These ages indicate that significant xenocrystic zircon populations occur in the dike. The youngest population of 2685 Ma could be xenocrystic, or possibly represent the age of emplacement of the dike.

SAMPLE C

A 5 m wide, diamondiferous lamprophyre dike is hosted by mafic metavolcanic rocks in Lalibert Township (UTM: Zone 16, 659875E, 5342030N) on a property held by Spider Resources Inc. on Highway 17, north of Wawa. Known as the Sandor occurrence, this dike contains rounded xenoliths of both crustal and mantle origin (Sage 2000). A U/Pb age of 2703±42 Ma was determined from titanite and rutile extracted from the dike matrix (Sage 2000). Titanite in a diamondiferous lamprophyre dike on the GQ diamond property east of Highway 17 provided a more precise age of 2674±8 Ma (Stott et al. 2002). A boulder-sized gneissic xenolith of possible mid- to deep-crustal origin was sampled (02JAA-0012). It is characterized by alternating plagioclase- and biotite-rich gneissic bands. A supracrustal origin cannot be ruled out, but is considered unlikely as quartz content appears to be minimal. An abundant, but very fine-grained, acicular green mineral (chlorite or amphibole) overgrows plagioclase. Additional minerals observed in thin section include epidote, ilmenite, rutile and titanite.

A number of interesting features were observed in heavy mineral separates from Sample C. Zircon is remarkably abundant and consists of 3 "populations":

1. large, colourless to light pink shards
2. equant to 2:1, colourless anhedral grains, many with a frosted appearance
3. pervasively cracked, mostly equant, brown and colourless anhedral grains, some consisting of a brown core and radially cracked colourless overgrowth

Zircon shards are the largest grain type, but it is not clear from what original morphology they were derived. Second, rutile and titanite are abundant in the sample and typically occur as aggregates of polycrystalline colourless titanite surrounding a core of yellowish-orange rutile. This reaction relationship is likely decompression related, and various stages are apparent, ranging from largely pristine rutile to polycrystalline titanite aggregates in which rutile has been completely consumed. L.M. Heaman described an identical reaction texture in the dike matrix (Wilson 2002) and attributed it to a metamorphic and/or metasomatic process. The analyzed grains are considered to be primary, not xenocrystic.

Five zircon fractions were analyzed, but 2 analyses failed due either to high common lead or extremely low uranium content. A colourless, spherical, frosted grain (population 2 above) and colourless prism fragments (population 3) provide an average ^{207}Pb/^{206}Pb age of 2684.9±1.4 Ma (80% p.o.f.) (Figure 10.2C), which is identical to the age of the youngest zircon population in the sample B dike (*see* "Sample B"). A colourless, low uranium content zircon shard is negatively discordant, but overlaps concordia with a ^{207}Pb/^{206}Pb age of 2679±7 Ma.

Common lead dominates a multigrain fraction of polycrystalline titanite lacking rutile cores (an end product of the rutile-to-titanite reaction) and no age was obtained. Two multigrain rutile fractions lacking titanite overgrowths were also analyzed, but these data are imprecise due to very low uranium content (<1 ppm) and discordant, most likely due to lead loss. All that can be concluded with certainty is that the rutile is either Archean or Paleoproterozoic. A lower closure temperature for rutile (~400°C) versus titanite (600±50°C) can explain the potentially younger age of rutile cores relative to titanite with ages previously determined. The earlier titanite data, the presence of a distinctive decompression reaction texture in both the dike and the xenolith, and U/Pb data reported here support the conclusion based on field relationships of an Archean age for the dike.

SAMPLE D

A sample of light gray-green, biotite-rich, diamondiferous lamprophyre (02JAA-0002) from the Gossan property held by Cabo Mining Corp. in Lorrain Township (UTM: Zone 17, 607688E, 5235197N) in the Cobalt area was sampled for U/Pb geochronology. The dike cuts pillowed mafic metavolcanic rocks and contains sparse xenoliths. Lamprophyre dikes and associated heterolithic breccias in this region have been recently described by Stott et al. (2002).

No diamonds were observed in the heavy mineral separate, and only 3 zircon grains were recovered. The largest is characterized by a euhedral overgrowth, whereas the other grains are euhedral and very small. These grains could be primary, inherited or represent laboratory contamination. Given this uncertainty, none were analyzed.

Colourless and light brown titanite fragments in the sample appear to represent a single population. Cracks and mineral inclusions are common, and overall grain quality is moderate to good. Three multigrain analyses are concordant to moderately discordant and appear to define a lead-loss line. The upper intercept age is 2664 +98/–17 Ma, and a concordant, abraded fraction has a ^{207}Pb/^{206}Pb age of 2667±27 Ma (Figure 10.2D). There is no indication that titanite is inherited (e.g., variations in grain habit, colour, or age reflecting multiple sources) and it is, therefore, concluded that the lamprophyre dike is Archean, with a minimum age circa 2664 Ma.

Samarium-Neodymium Isotopes

Recently determined Sm-Nd isotopes from diamondiferous lamprophyre dikes from the Michipicoten greenstone belt and the Abitibi greenstone belt range from ε_{Nd} 0.3 to ε_{Nd} 5.0 (N = 5, avg. = 3.0, T = 2.7 Ga; R.V. Conceição, Universidade Federal do Rio Grande do Sul, unpublished data, 2003). In conjunction with the geochemical features of the diamondiferous lamprophyres discussed above, these isotopic values suggest derivation from more primitive mantle sources than non-diamondiferous lamprophyres (*see* above). In addition, the Sm-Nd isotopic values for ultramafic xenoliths from diamondiferous lamprophyres range from ε_{Nd} 3.9 to ε_{Nd} 7.7 (N = 4, avg. = 5.0, T = 2.7 Ga; R.V. Conceição, Universidade Federal do Rio Grande do Sul, unpublished data, 2003). This suggests derivation from even more depleted mantle than the diamondiferous lamprophyres, similar in value to the most isotopically primitive Abitibi komatiite (Ayer et al. 2002).

DISCUSSION AND CONCLUSIONS

An age of 2701.4±2.1 Ma for the intermediate volcanic unit (Sample A) hosting the diamondiferous lamprophyre dikes and heterolithic breccias is consistent with that of the cycle 3 volcanic rocks of the Michipicoten greenstone belt (Turek, Sage and Van Schmus 1992). It is virtually the same age, but is considerably more precise, than the 2701±7.7 Ma determined for cycle 3 crystal tuffs at McCormic Lake, several kilometres to the north (Turek, Sage and Van Schmus 1992).

The different zircon age populations (i.e., 2715 Ma, 2706 Ma, 2689 Ma and 2685 Ma) from lamprophyre dike B and a xenolith in the Sandor lamprophyre dike (sample C), which both intrude the cycle 3 volcanic rocks, suggests a larger range of ages may be present in the crustal rocks sampled by the dikes than had been previously recognized in this area. These populations may represent contamination from cycle 3 volcanic units (Turek, Sage and Van Schmus 1992), late-tectonic sedimentary units (Corfu and Sage 1992) and possibly lower crustal sources. The youngest zircon age population of 2685.0±1.0 Ma in the sample B dike is identical to 2684.9±1.4 Ma zircons in the gneissic xenolith from the Sandor dike (sample C). These provide a maximum age for emplacement of the dikes, but are probably not the magmatic age, as titanites from a dike in Musquash Township give a somewhat younger age of 2674±8 Ma (Stott et al. 2002). However, it is also possible that the titanite ages could have been modified by a later metamorphic event. At this time, it is uncertain whether the youngest xenocrystic zircon population in the dike and gneissic xenocryst represents contamination from supracrustal sources, a lower crustal source, or both. However, the preliminary Sm-Nd isotopic data from the gneissic xenolith (sample C) shows strongly negative ε_{Nd} values (R.V. Conceição, Universidade Federal do Rio Grande do Sul, unpublished data, 2003) suggesting the xenolith was derived from an ancient enriched source, most likely from the lower crust. The Abitibi greenstone belt diamondiferous dike has a less certain age as titanite gives a relatively imprecise age of 2667±27 Ma and is considered to be a minimum age for emplacement of this dike.

The absolute age(s) of the diamondiferous heterolithic breccias is uncertain. These breccias typically have a close spatial association with diamondiferous lamprophyre dikes. However, they are clearly somewhat older than the dikes as they are commonly intruded by the dikes. In addition, the breccias are commonly richer in diamonds than the dikes and locally appear to be conformable with the surrounding volcanic units in the Michipicoten greenstone belt (cycle 3?). Thus, in order to help determine the age of these economically important units, and to help better understand their petrogenesis, samples of the breccias and their host volcanic rocks have been collected for further geochronology.

The chemical and isotopic compositions, petrography and field relations of the diamond-associated lamprophyre dikes indicate they are derived from similar magmas that have been variably contaminated by an ultramafic component. This is an important constraint because shoshonitic lamprophyres are generally derived from relatively shallow upper mantle sources, typically from the spinel lherzolite field at depths of less than 80 km. As a result, the parental magmas are usually generated above the typical diamond stability field. In fact, the lamprophyric magmas themselves were derived from subduction-modified asthenosphere that remained beneath the greenstone belts (Wyman and Kerrich 2002).

If the slab-breaching magma was contaminated by the ultramafic contaminant identified in the dikes, then, a magma mixing event above a (fossil) subducted slab is required. The scenario requires that the mixing event immediately predated ascent of diamond-bearing shoshonitic magmas in order that the diamonds be preserved. More plausibly, the diamonds formed at relatively shallow depths (80 to 100 km) in a subduction-generated low-temperature window located in subducted or underplated oceanic crust (e.g., Barron et al. 1996). Ascent of lamprophyric magmas immediately following subduction allowed for entrainment of the diamonds during Neoarchean orogenesis.

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11. Project Unit 02-007. Paleomagnetic Studies of Mafic Dikes in the Vicinity of Lake Nipigon, Northwestern Ontario

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INTRODUCTION

This article summarizes some results of an ongoing project (Stott and Halls 2002) that documents the paleomagnetic characteristics of Proterozoic mafic dike swarms in northern Ontario. This complements the U/Pb geochronology of selected dikes (Davis and Stott, this volume). Some objectives of this study are listed below.

1. To paleomagnetically and geochemically distinguish Keweenawan dikes of 1100 Ma age from the older Marathon dike swarm (circa 2110 Ma) in the vicinity of Lake Nipigon. One of the questions, to which we hope to provide some insight, is how widespread are dikes of Keweenawan age in this region.
2. Kimberlite pipes might occur in spatial association with some suitably oriented mafic dike swarms (Stott and Halls 2002; Stott 2003). Consequently, there is a need, to which this project is contributing, to identify the dike swarms and regional, post-Archean crustal uplifts across Ontario (Halls and Zhang 2003).
3. One of the aims of this project is to discover possible feeder systems for the diabase sills and sheets (1110 Ma) that underlie and surround Lake Nipigon, in order to establish the provenance of platinum group element (PGE) mineralization recently found in association with these rocks.
4. Documenting the regional mafic dike swarms in Ontario also contributes to the identification of associations or distinctions amongst different clusters of dikes and to the location of Proterozoic mantle plumes, which commonly occur where radiating swarms converge (e.g., Buchan et al. 2003; Ernst and Buchan 1997).

LOCATION

Samples from Proterozoic mafic dikes were obtained at sites widely distributed east of Lake Nipigon and some northwest of Lake Nipigon as shown in Figure 11.1.

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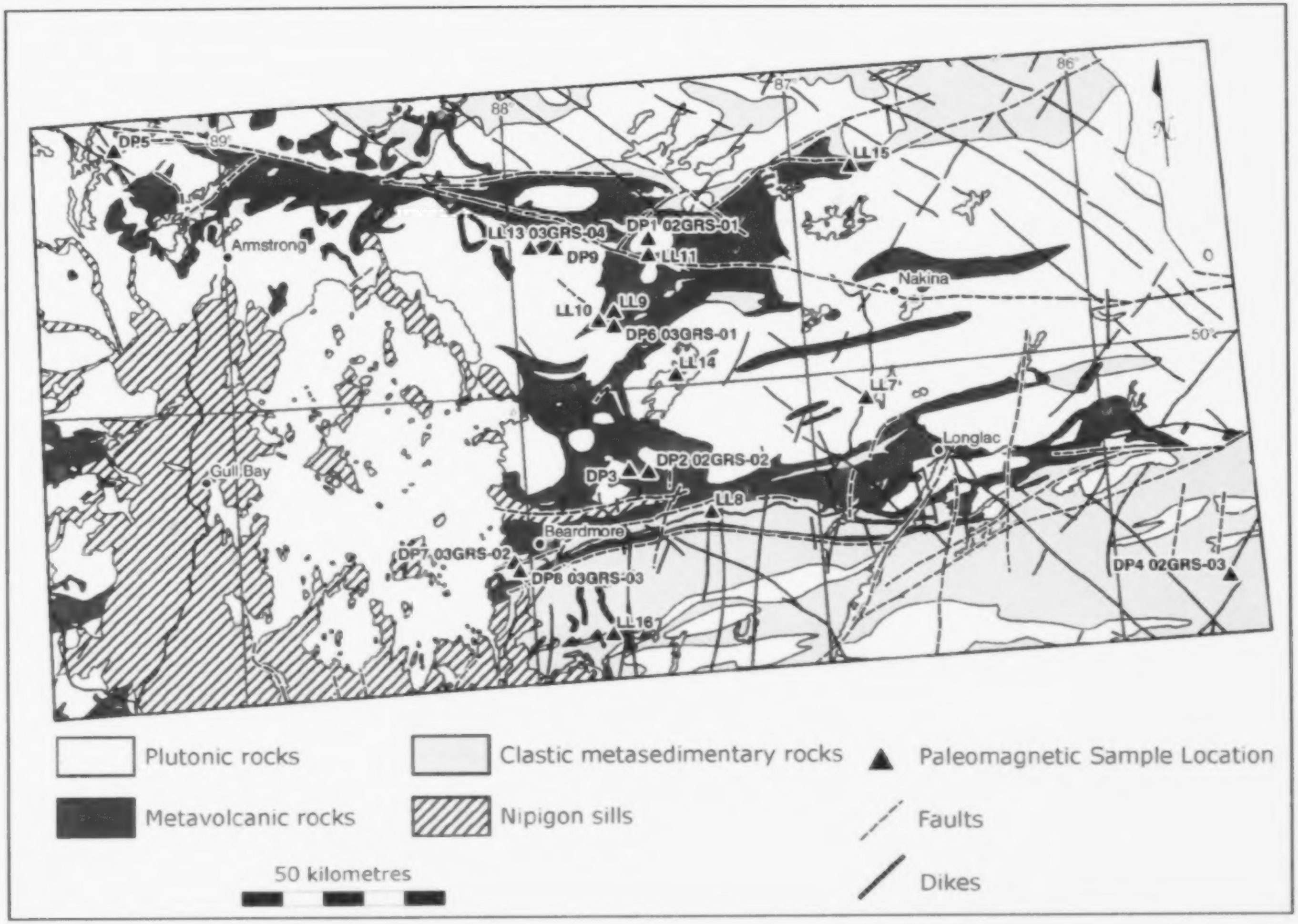
N
86°
87°
88°
89°
50°
DP5
Armstrong
LL13 03GRS-04
DP9
DP1 02GRS-01
LL11
LL15
Nakina
LL10
LL9
DP6 03GRS-01
LL14
LL7
Gull Bay
DP3
DP2 02GRS-02
Longlac
LL8
Beardmore
DP7 03GRS-02
DP8 03GRS-03
LL16
DP4 02GRS-03
Plutonic rocks
Metavolcanic rocks
Clastic metasedimentary rocks
Nipigon sills
Paleomagnetic Sample Location
Faults
Dikes
50 kilometres

Figure 11.1. Locations of Proterozoic mafic dikes sampled in 2002 and 2003 in the region around Lake Nipigon.

Table 11.1. Paleomagnetism results of northwest-striking Matachewan mafic dikes.

Site	Latitude (N)	Longitude (W)	Width (m)	Strike	Declination	Inclination	n	k	α_{95}
LL1	49°48.238′	86°33.078′	40	285°	202.5°	−14.8°	9	72	6.1
LL2	49°44.699′	86°47.002′	35	280°	195.6°	−14°	8	28	10.6
LL3	49°47.200′	86°34.600′	20	310°	196.9°	−21.6°	9	92	5.4
LL4	49°40.930′	86°40.249′	> 7?	?	189.2°	−18°	5	61	9.9
LL5	49°47.919′	86°46.071′	>40	?	198.4°	−20.1°	7	11	19
LL6	49°47.487′	86°42.084′	> 2	295°			erratic		
LL8	49°42.432′	87°22.376′	25	285°	183.1°	−14.3°	8	174	4.2
LL10	50°09.959′	87°39.477′	25	300°	187.5°	−16.8°	9	73	6
LL11	50°17.339′	87°31.728′	10	304°	183.4°	−28.4°	7	147	5
LL13	50°19.758′	87°56.146′	16	320°	174.2°	−16.9°	10	47	7.1
LL14	50°01.164′	87°27.742′	25	330°	192.1°	−23°	7	91	6.4
LL15	50°27.329′	86°47.858′	25	330°	188.3°	−10.3°	11	38	7.6
OL1	50°49.000′	87°09.000′	34	307°	188.2°	−20.4°	7	140	5.1
OL2	50°48.000′	87°11.500′	34	311°	182.7°	−29.2°	6	38	11
OL3	50°48.000′	87°12.000′	21	307°	189.3°	−28.2°	5	24	15.9
OL4	50°52.000′	87°10.500′	4	313°	181.7°	−14.3°	5	110	7.1

Notes: LL5 does not have clear field relationships and has not been used in the calculation of the mean paleomagnetic remanence direction. k = paleomagnetic precision parameter; other symbols defined in the text.

Table 11.2. Paleomagnetism results of non-Matachewan mafic dikes.

Site	Latitude (N)	Longitude (W)	Width (m)	Strike	Declination	Inclination	n	k	α_{95}
DP1	50°19.462′	87°1.218′	60	045°	scattered data				
DP2	49°48.209′	87°34.524′	38	010°	scattered data				
DP3	49°48.842′	87°38.901′	27	010°	120°	−65.1°	7	315	3.4
DP4	49°27.567′	85°37.374′	100	037°	104.2°	−57.2°	4	161	7.3
DP5	50°35.511′	89°22.146′	100	320°	114.9°	−70.8°	6	531	2.9
DP6	50°9.230′	87°42.416′	50	032°	128.2°	−57.7°	4	284	5.5
DP7	49°37.158′	88°3.409′	13	060°	magnetic host; erratic results				
DP8	49°36.380′	88°2.748′	20	005°	90.3°	−71.3°	6	386	3.4
DP9	50°19.019′	87°50.447′	26	040°	126.2°	−51°	3	23	26
DP10	50°34.818′	89°24.979′	3.5	320°	76.5°	−61.4°	2	146	21
LL7	49°56.039′	86°48.595′	0.25	300°	297.1°	65.1°	8	40	8.8
LL12	50°34.906′	89°25.006′	1	297°	95.9°	−70.4°	6	685	2.6
LL16	49°27.002′	87°44.743′	?	325°	105.9°	−73.7°	4	132	8
KP20	40°08.5′	85°57.1′	60	060°	98°	−54.9°	15	50	5.5

Notes: k = paleomagnetic precision parameter; other symbols defined in the text.

SAMPLING PROCEDURES

Samples, oriented using both a magnetic and sun compass, were collected from north-northeast and northwest-striking dikes, which are the most common dike trends in the area. Typically, 5 to 10 samples were collected from each site with emphasis on chilled margins where, due to the small size of magnetite carriers, primary remanence is most likely to survive. The majority of samples were collected by field drilling, but a few, from more finely jointed chilled margins, were collected as blocks, which were then subsequently cored in the laboratory. After the cores were cut into cylindrical specimens 2.45 cm in length and in diameter, their natural remanent magnetization (NRM) was measured on a modified DIGICO magnetometer, after each incremental increase in alternating field demagnetization to remove secondary magnetization components. The data were then analyzed using principal component analysis (Kirschvink 1980) in combination with stereoplots and vector diagrams, following normal paleomagnetic procedures. Preliminary results are reported in 2 tables. Table 11.1 includes only results from northwest-striking dikes that have paleomagnetic signatures characteristic of Matachewan dikes 2446 Ma in age. Table 11.2 summarizes results from all remaining, non-Matachewan dikes.

RESULTS

Matachewan Dikes

Our study has added a further 12 paleomagnetic sites to the Matachewan dike database. The sites all come from the westernmost part of the Matachewan swarm and will help test if the amount of relative rotation suffered by the dikes across the Kapuskasing Structural Zone (Bates and Halls 1991) increases toward the west. This might be suggested by the change in average trend of the dikes from approximately 305°, west of longitude 86°, to approximately 325°, east of longitude 86°, in the Hornepayne area. The sampled dikes only partially overlap along strike with those farther east in the Hornepayne area, so that the paleomagnetic results are not strictly comparable. The mean direction for sites west of longitude 86° is D = 188°, I = –18.7°, α_{95} = 4.7°, n = 13, where D is declination, I is inclination, α_{95} is the radius of the 95% confidence circle about the mean, and n is the number of sites. Our new data have been combined with those (OL1 to OL4 in Table 11.1) previously reported from Ogoki Lake (Bates and Halls 1991). All sites have reversed (R) magnetization. East of longitude 86°, in the Hornepayne area, D = 189.9°, I = –27.7°, α_{95} = 3.8°, n = 10 (Bates and Halls 1991). One-fifth of these sites is of N polarity and their remanence directions have been reversed in the mean calculation. In contrast to the Hornepayne data, those from the Nipigon area have exclusively R polarity and a significantly lower inclination. In order to get a true comparison with the Hornepayne data more dikes need to be sampled north of Tashota and Nakina (*see* Figure 11.1).

The only paleomagnetic data from more easterly Matachewan dikes that may be comparable with those from the Nipigon suite come from the vicinity of Ranger Lake, east of Lake Superior and on the opposite side of the Kapuskasing Structural Zone. Here data of comparable quality (n, number of samples in a site, where $4 \geq \alpha_{95} \leq 15°$) give D = 211.1°, I = –16.6°, α_{95} = 10.9° and n = 6, where 3 out of 20 dikes were of N polarity. The significantly lower D and similar I of the Nipigon dikes suggest that they have rotated counterclockwise about 20° with respect to the Ranger Lake area. However, good-quality Ranger Lake data (Halls and Shaw 1988) are relatively few.

Biscotasing and Marathon Dikes

Dikes of north-northeast trend occur widely across the Nipigon embayment and may belong to 1 of 2 known dike swarms, the northeast-striking Biscotasing swarm (circa 2170 Ma: Halls and Davis, in press) and the north-northeast striking Marathon swarm (circa 2110 Ma: Buchan, Halls and Mortensen 1996). Marathon dikes yield 2 polarities (Buchan, Halls and Mortensen 1996): a younger R polarity ($D = 133.5°$, $I = -50.7°$, $\alpha_{95} = 6.8°$, $n = 12$), with a U/Pb age of 2101±1.6 Ma (Hamilton et al., 2002) and an older N polarity suite ($D = 294.8°$, $I = 57.0°$, $\alpha_{95} = 6.3°$, $n = 16$), with a U/Pb age of 2121+14/−7 Ma (Buchan, Halls and Mortensen 1996). Biscotasing dikes, east of the Kapuskasing Structural Zone, yield a direction of $D = 266.4°$, $I = 62°$, $\alpha_{95} = 8.4°$, $n = 6$ (Buchan, Mortensen and Card 1993). Those west of the Kapuskasing Structural Zone have a direction of $D = 250.3°$, $I = 58.0°$, $\alpha_{95} = 9.0°$, which suggests that they, like the Matachewan dikes, have also been rotated counterclockwise with respect to dikes of the same age east of the Kapuskasing Structural Zone (Halls and Davis, in press).

BISCOTASING DIKES

Site DP 4 is in the 100 m wide northeast-striking Hillsport dike, which has a U/Pb age of 2170.7±1.1 Ma (Davis and Stott, this volume). This dike is, therefore, a member of the Biscotasing swarm, but differs in that it is the first to have R polarity. It has a paleomagnetic direction ($D = 104°$, $I = -57°$, *see* Table 11.2) that is only about 10° away from being antipodal to N polarity Biscotasing dikes. This dike was originally thought to be part of the 1141 Ma Abitibi dike swarm (Ernst and Buchan 1993, their site A1). The dike is presently being quarried for railroad ballast. Another northeast-striking dike (KP20) lies at the western end of Swill Lake, west of Manitouwadge and is lithologically similar to the Hillsport dike and is about 60 m wide. It gives a paleomagnetic direction of $D = 98°$, $I = -54°$, $\alpha_{95} = 5.5°$, $n = 15$, which is virtually identical to the Hillsport dike. This suggests it is a southwest continuation of the Hillsport dike, a correlation not readily apparent from aeromagnetic data, owing to highly magnetic host rocks in the vicinity of Manitouwadge. The Manitouwadge site is readily accessible by road and would represent a potential quarry site to further extract railroad ballast.

MARATHON DIKES

Two dikes (sites DP1 and 2) provided U/Pb ages of 2112±9 Ma and 2109.1±1.6 Ma, respectively (Davis and Stott, this volume), which identified them as members of the Marathon swarm, but unfortunately both were paleomagnetically unstable. However, for DP1, the data suggest N polarity rather than R polarity. The data from DP2 were too scattered to assess any polarity, likely the result of lightning strikes. Based purely on their paleomagnetic direction, other dikes ascribed to the Marathon swarm are those at sites DP6 and DP9. Site DP4 was ambiguous, as its paleomagnetic direction was intermediate between the mean for Marathon dikes and Nipigon diabase, but it occurred within a few hundred metres of Marathon dike site DP2, which had a similar thickness and trend.

POSSIBLE FEEDER SYSTEMS ASSOCIATED WITH NIPIGON DIABASE SILLS

One of the aims of the project was to discover possible feeder systems for the Nipigon diabase sills and sheets (1110 Ma) that underlie and surround Lake Nipigon, in order to establish the provenance of platinum group element (PGE) mineralization recently found in association with these rocks. The Nipigon diabase gives a well-defined paleomagnetic direction ($D = 111.0°$, $I = -72.0°$, $\alpha_{95} = 2.5°$), which is a mean of 5 independent studies (Halls and Pesonen 1982). It is clearly distinct from the direction found in R polarity Marathon dikes.

An unsuccessful search was made around Smooth Rock Lake, west of Lake Nipigon, for outcrops of Matachewan dikes and the north-northwest-striking Pickle Crow dike. Instead, 2 northwest-striking dikes were found (sites LL12 and DP 10), but both gave Nipigon diabase paleomagnetic directions. At site DP5, a dike-like body was sampled, which also appeared to have a northwest strike along its southern contact, and it too gave a typical Nipigon diabase paleomagnetic signature. The possibility that overlying Nipigon diabase sheets had magnetically reset older northwest-striking Matachewan dikes is a possibility, but there is no indication of more than one component of magnetization in the rocks. We believe that the magnetization is primary, indicating a possible northwest-trending feeder system to Nipigon diabase in this area.

At site LL16 east of Lake Nipigon, a large discontinuous roadside outcrop of diabase with intervening areas of host rock granite suggested a family of dikes, although contacts were not exposed. One diabase outcrop included a feldspar phenocryst-rich layer that had a northwest strike, and contacts, although not exposed, were consistent with this trend. The results gave a clear Nipigon diabase signature, which suggests that the northwest-trending feeder system seen at Smooth Rock Lake is areally more extensive. At site DP8, a north-trending dike gave an excellent Nipigon diabase paleomagnetic direction. This dike is within a few hundred metres of a Nipigon sill, so it is possible that it may be a Marathon dike that has been heated by an overlying sill that has since been eroded away. An alternative interpretation is that the dike is Keweenawan and, therefore, part of a north-south-trending dike feeder system that has often been anticipated in support of Nipigon sills representing the products of an aulacogen, which immediately preceded opening of the main Lake Superior Rift system. Ongoing petrographic and geochemical studies may resolve the issue.

Only one truly anomalous site (LL7) was discovered in which the dike could not be assigned to any of the defined intrusive episodes. A series of west-northwest-striking diabase dikelets, several no more than a few centimetres wide, gave a well-defined direction of $D = 297.1°$, $I = 65.1°$, $\alpha_{95} = 3.4°$, $n = 8$. The dike trend is similar to that of the west-northwest-striking Wabigoon dike swarm of unknown absolute age, west of Lake Nipigon, from which one paleomagnetic site gave a magnetization direction ($D = 267.0°$, $I = 79.8°$, $\alpha_{95} = 2.0°$, $n = 4$; Dunlop 1983), only 20° from that given by site LL7.

CONCLUSION

Preliminary paleomagnetic data have identified 5 different ages of diabase dike intrusions in the Lake Nipigon region, and show that paleomagnetism provides a rapid and relatively cheap way to discriminate between the various ages of dikes. U/Pb geochronology has confirmed significant age differences between dikes that are also dissimilar in their paleomagnetic directions. Kimberlite pipes might occur in spatial association with some suitably oriented mafic dike swarms (Stott and Halls 2002; Stott 2003).

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12. Project Unit 02-007. Geochronology of Two Proterozoic Mafic Dike Swarms in Northwestern Ontario

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[2]Precambrian Geoscience Section, Ontario Geological Survey

INTRODUCTION

Work is currently in progress to improve our limited understanding of the paleomagnetic and geochronologic signature of the numerous mafic dike swarms in northwestern Ontario. This article reports 3 new age determinations for Proterozoic mafic dikes in northwestern Ontario, which provide valuable constraints on the ages of paleomagnetic determinations for these dikes (Halls and Stott, this volume). The results are based on U-Pb data on baddeleyite obtained from 2 north- and north-northeast-striking mafic dikes, east of Lake Nipigon, and from 1 northeast-striking dike near Hillsport, north of Manitouwadge (Figure 12.1).

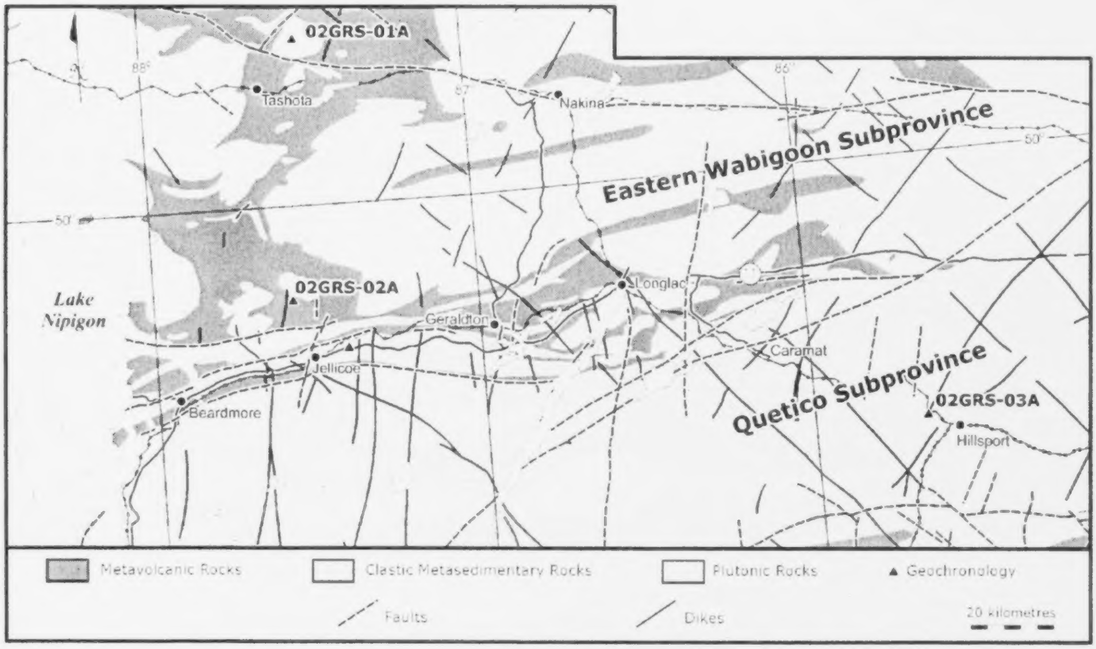
02GRS-01A
88°
87°
86°
50°
50°
Tashota
Nakina
Eastern Wabigoon Subprovince
Lake Nipigon
02GRS-02A
Longlac
Geraldton
Jellicoe
Beardmore
Caramat
Quetico Subprovince
02GRS-03A
Hillsport
Metavolcanic Rocks
Clastic Metasedimentary Rocks
Plutonic Rocks
Geochronology
Faults
Dikes
20 kilometres

Figure 12.1. Locations of Proterozoic mafic dikes sampled for geochronology between Lake Nipigon and Hillsport.

Summary of Field Work and Other Activities 2003,
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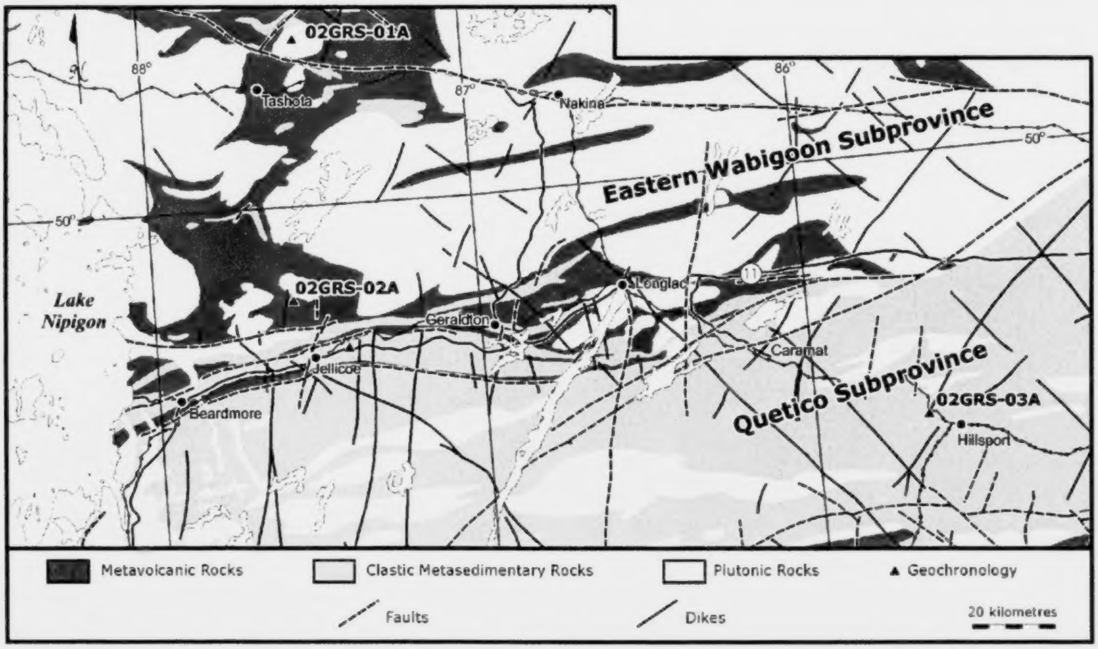
02GRS-01A
88°
87°
86°
Tashota
Nakina
Eastern Wabigoon Subprovince
50°
50°
Lake Nipigon
02GRS-02A
Longlac
11
Geraldton
Jellicoe
Beardmore
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Hillsport
Metavolcanic Rocks
Clastic Metasedimentary Rocks
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▲ Geochronology
Faults
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Figure 12.1. Locations of Proterozoic mafic dikes sampled for geochronology between Lake Nipigon and Hillsport.

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SAMPLE LOCATIONS

Sample 02GRS-01A

Sample 02GRS-01A (*see* Figure 12.1 for sample locations) was obtained from a north-northeast-striking mafic dike that crosses the Deeds pluton in the northern part of the Onaman–Tashota greenstone belt (*see* Figure 12.1). The 60 m wide dike strikes 025° and dips 80°W across a hornblende monzonite phase of the Deeds pluton. It is well exposed in a clear-cut area, close to a logging road. The sample is taken from the medium-grained and vari-textured hornblende porphyritic centre of the dike.

Sample 02GRS-02A

A north-striking mafic dike was sampled beside the Kinghorn Road at kilometre 24, north of Jellicoe (*see* Figure 12.1). This dike is about 29 m wide and strikes 005° and dips 80°W. The sample is from the coarsest inner part of the dike with mineral grains that are 2 to 3 mm in diameter.

Sample 02GRS-03A

A northeast-striking mafic dike, previously mapped by Milne (1964), is located 5 km west of the small village of Hillsport, north of Manitouwadge (*see* Figure 12.1). It is 100 to 133 m wide and strikes 040°. This dike is one of a set of widely spaced northeast-striking dikes in east-central Ontario that can be traced aeromagnetically for many tens of kilometres and also extend under the James Bay Lowland (Ontario Geological Survey 1992). The Hillsport dike is currently being quarried as a source of railroad ballast. Sample 02GRS-3A was taken from the coarsest, gabbro to leucogabbro portion of the dike, with grains 2 to 4 mm in diameter and feldspar laths up to 1 cm long.

METHODS

The samples weighed about 10 to 15 kg and were crushed using a jaw crusher followed by a disk mill. Initial separation of heavy minerals was carried out with a Wilfley® table. This was followed by paramagnetic separations with a Frantz® isodynamic separator, and density separations using bromoform and methylene iodide. In some cases, this method failed to yield baddeleyite or zircon. An alternate method was tried in which small amounts of rock powder (ca. 100 g) were passed over the Wilfley® table following the method of Söderlund and Johansson (2002). After careful examination of the heavy mineral fraction, a few grains of baddeleyite were recovered. Baddeleyite occurs as tiny (1 µg or less), flat, brown, fragments that can easily be lost during conventional mineral separation, possibly by sticking to larger grains. Unlike zircon, baddeleyite is not susceptible to significant lead loss, so laboratory abrasion (Krogh 1982), which would not have been possible with such tiny grains, is not required. The freshest looking baddeleyite crystals, based on high lustre, were chosen for analysis. Other crystals have a dull appearance possibly because of alteration, which may include partial replacement by zircon. Weights of single-grain mineral fractions were estimated from digital photomicrographs (Matthews and Davis 1999). Estimated weights should be accurate to about ±20%. This affects only U and Pb concentrations, not age information, which depends only on isotope ratio measurements (Table 12.1).

Mineral grains were washed in HNO_3 prior to dissolution. ^{205}Pb-^{235}U spike was added to the dissolution capsules during sample loading. Single baddeleyite grains were dissolved using concentrated HF in Teflon™ bombs at 200°C (Krogh 1973) then redissolved in 3N HCl to ensure equilibration with the spike. Total solutions were loaded directly onto Re filaments with silica gel. Lead and uranium were analyzed on a VG354 mass spectrometer using a Daly collector in pulse counting mode. The mass discrimination correction for the Daly detector is constant at 0.07% per AMU (atomic mass unit). Thermal mass discrimination corrections are 0.10% per AMU. Dead time of the measuring system was 22.9 nanoseconds as determined using the NBS SRM 982 Pb standard.

RESULTS

Results of U/Pb isotopic analyses are given in Table 12.1 (errors at 2 sigma (2σ)). Data are plotted on concordia diagrams in Figure 12.2 with 2σ error ellipses. Analyses are numbered on the diagrams according to Table 12.1. Average age errors are given at 95% confidence levels and are based on averaging $^{207}Pb/^{206}Pb$ ages using the program of Davis (1982). This procedure has generally been found to give correct ages when applied to near-concordant data from baddeleyite or abraded zircon. Probabilities of fit are expected to be 50% on average for random data with correctly chosen analytical errors. All age errors are quoted at the 2σ level.

02GRS-01A: North-Northeast-Trending Mafic Dike East of Lake Nipigon

Only 2 tiny baddeleyite grains could be found in this sample after several hours of searching (Figure 12.3a). Total radiogenic Pb contents in these grains were about 3 and 8 pg. Fortunately, blanks were at the sub-picogram level so they could be dated with reasonable precision. The analyses gave concordant and near-concordant data with overlapping $^{207}Pb/^{206}Pb$ ages that average to 2112±9 Ma (51% probability of fit: Figure 12.2a). This is likely to represent the age of dike emplacement.

02GRS-02A: North-Northeast-Trending Mafic Dike East of Lake Nipigon

A few tiny baddeleyite grains were recovered from this sample. They are mostly flat brownish fragments. Three single grains that appeared fresh, as shown by shiny surfaces, were analyzed (Figure 12.3b). Isotopic ratios from analysis 3 (DWD4346) changed during the course of the mass spectrometer analysis. This was likely caused by a source of common Pb on the filament that was only partially mixed with the sample, such as a grain of dust. Because all Pb ratios are measured together within a single data block, reduced concordia data can be averaged between the blocks and a correct standard deviation calculated, despite the dispersion of the measured ratios. All 3 analyses gave concordant to near-concordant data with overlapping $^{207}Pb/^{206}Pb$ ages that average to 2109.1±1.6 Ma (73% probability of fit: Figure12.2b). This probably represents the age of emplacement of the dike.

02GRS-03A: Northeast-Trending Diabase Dike, Hillsport Area

A few baddeleyite flakes were recovered from this sample as well as a few tiny grains of zircon, which are probably inherited from wall rocks. All the baddeleyite grains have dull surfaces and do not appear as fresh as in the previous samples. The 3 freshest looking baddeleyite grains were analyzed (Figure 12.3c). These gave slightly discordant data, but the $^{207}Pb/^{206}Pb$ ages agree within error. Their average age of 2170.7±1.1 Ma (52 % probability of fit: Figure 12.2c) is probably the age of emplacement of this dike.

Table 12.1. U/Pb isotopic data on baddeleyite from mafic dikes.

No.	Description	Weight (mg)	U (ppm)	Th/U [a]	Pb_{Tot} [b] (pg)	Pb_{Com} [c] (pg)	$\frac{^{207}Pb}{^{204}Pb}$	$\frac{^{206}Pb}{^{238}U}$	2σ	$\frac{^{207}Pb}{^{235}U}$	2σ	$^{207}Pb/^{206}Pb$ Age (Ma)	2σ	% Disc. [d]	Corr. Coeff.
1.	**02GRS-01A, on Deeds pluton** (UTM: Zone 16, 462964E, 5574826N)														
1	1 badd. brn	0.00005	415.0	0.04	7.7	0.73	105.6	0.3770	0.0023	6.817	0.064	2113	11	2.8	0.7466
2	1 badd. brn	0.00003	278	0.06	3.2	0.53	66.31	0.3844	0.0057	6.921	0.138	2106	20	0.5	0.8146
2.	**02GRS-02A, Kinghorn Rd** (UTM: Zone 16, 458602E, 5516981N)														
1	1 badd. eq. fresh. dk brn	0.0010	215	0.12	83.2	0.8	857.9	0.3859	0.0018	6.960	0.032	2109.0	3.8	0.3	0.8947
2	1 badd. fresh. dk brn	0.0005	448	0.06	84.9	0.6	1226.2	0.3841	0.0021	6.929	0.038	2109.5	2.3	0.8	0.9715
3a	1 badd. flat. fresh. brn	0.0003	721	0.04	81.1	1.2	609.6	0.3820	0.0020	6.874	0.035	2104.9	3.8	1.1	0.9122
3b	1 badd. flat. fresh. brn	0.0003	721	0.03	81.1	1.5	467.1	0.3829	0.0012	6.901	0.023	2107.6	4.1	1.0	0.7424
3c	1 badd. flat. fresh. brn	0.0003	721	0.02	80.9	1.8	412.7	0.3822	0.0010	6.885	0.023	2106.8	3.1	1.1	0.8477
3d	1 badd. flat. fresh. brn	0.0003	721	0.02	81.0	1.9	373.5	0.3832	0.0014	6.901	0.027	2106.0	4.1	0.8	0.8159
3.	**02GRS-03A, Hillsport** (UTM: Zone 16, 599810E, 5479539N)														
1	1 badd. flat. dull	0.0010	783	0.16	311.5	0.6	4378.4	0.3916	0.0011	7.319	0.022	2171.3	1.8	2.2	0.9429
2	1 badd. flat. dull	0.0005	789	0.06	154.5	0.9	1501.0	0.3952	0.0014	7.381	0.027	2169.8	2.0	1.2	0.9518
3	1 badd. flat. dull	0.0003	1234	0.10	146.7	3.1	420.8	0.3962	0.0009	7.402	0.023	2170.5	3.0	1.0	0.8339

NOTES:

Fractions are ordered from highest to lowest $^{207}Pb/^{206}Pb$ age
[a] Th/U calculated from radiogenic $^{208}Pb/^{206}Pb$ ratio and $^{207}Pb/^{206}Pb$ age assuming concordance.
[b] Pb_{tot}, total lead minus blank
[c] Pb_{Com}, total measured common lead, assuming the isotopic composition of laboratory blank: 206/204 = 18.221; 207/204 = 15.612; 208/204 = 39.360 (errors of 2%).
[d] %Disc, percent discordance for the given $^{207}Pb/^{206}Pb$ age.
Uranium decay constants are *from* Jaffey et al. (1971).

Abbreviations: badd, baddeleyite; brn, brown; dk, dark; eq, equant; UTM, Universal Transverse Mercator coordinates North American Datum 1983 (NAD 83).

Laboratory numbers for analytical samples:
for 02GRS-01A: 1 = DWD4422; 2 = DWD4423;
for 02GRS-02A: 1 = DWD4344; 2 = DWD4345; 3a = DWD4346a; 3b = DWD4346b; 3c = DWD4336c; 3d = DWD4346d;
for 02GRS-03A: 1 = DWD4347; 2 = DWD4348; 3 = DWD4349.

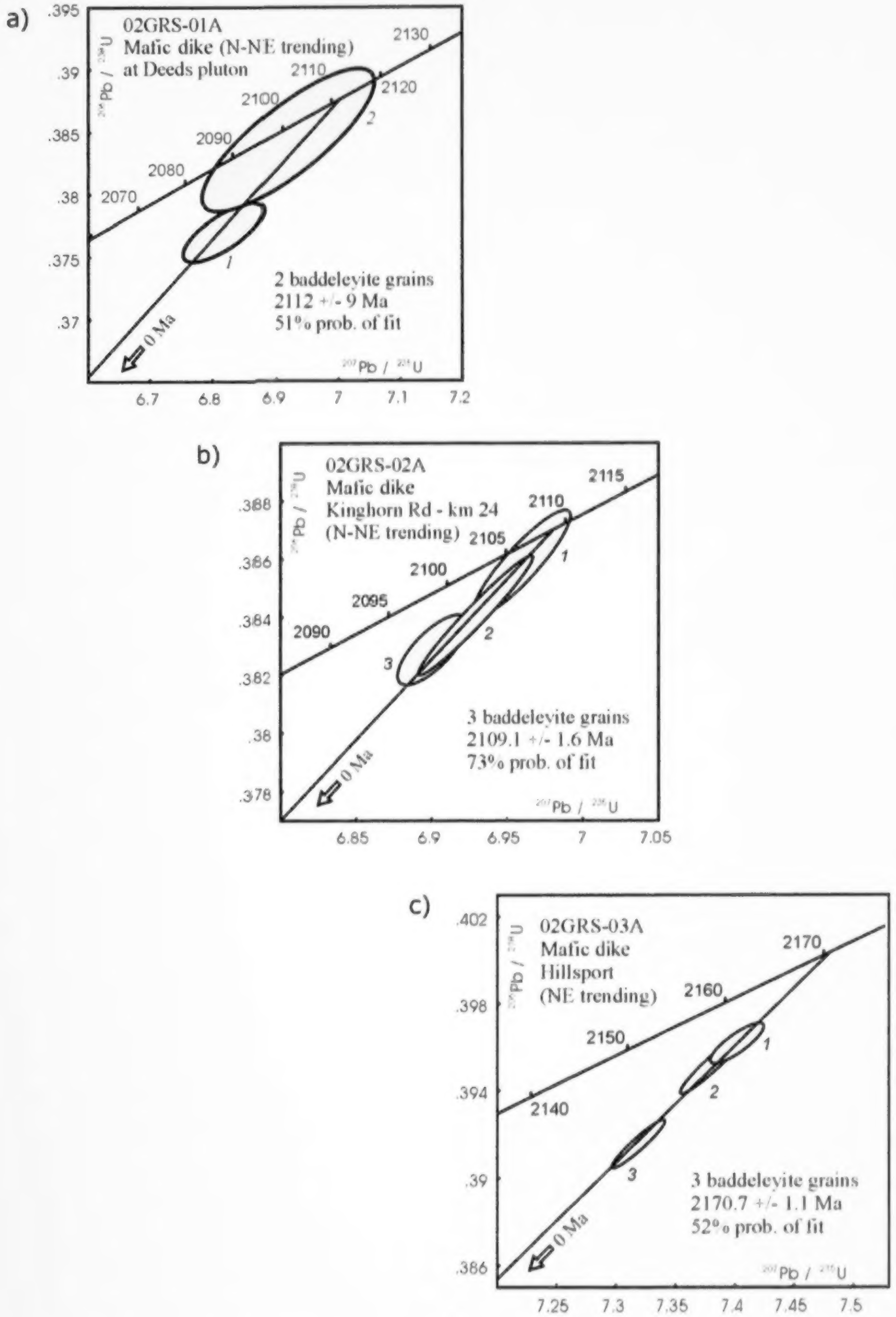

Figure 12.2. Concordia diagrams showing U/Pb analyses for baddeleyite from samples of mafic dikes: a) crossing the Deeds pluton; b) at km 24 on Kinghorn Rd; and c) 5 km west of Hillsport.

DISCUSSION

Geochronologic analysis of extremely small baddeleyite crystals containing a few picograms of radiogenic lead is feasible if analytical blanks can be kept at the sub-picogram level. The precision of such ages is sufficient to distinguish between dike swarms. The major problem with determining the ages of mafic dikes is recovery of baddeleyite because of the typical small size and tabular habit of the crystals. It is recommended that rock sample sizes be restricted to no more than a few kilograms and mineral separation be carried out using special methods that do not involve working with dry sample. A few hundred grams of powder may be the largest amount that it is practical to work with using such methods, but baddeleyite should be recoverable from such small amounts in many cases, especially if it is visible in thin section.

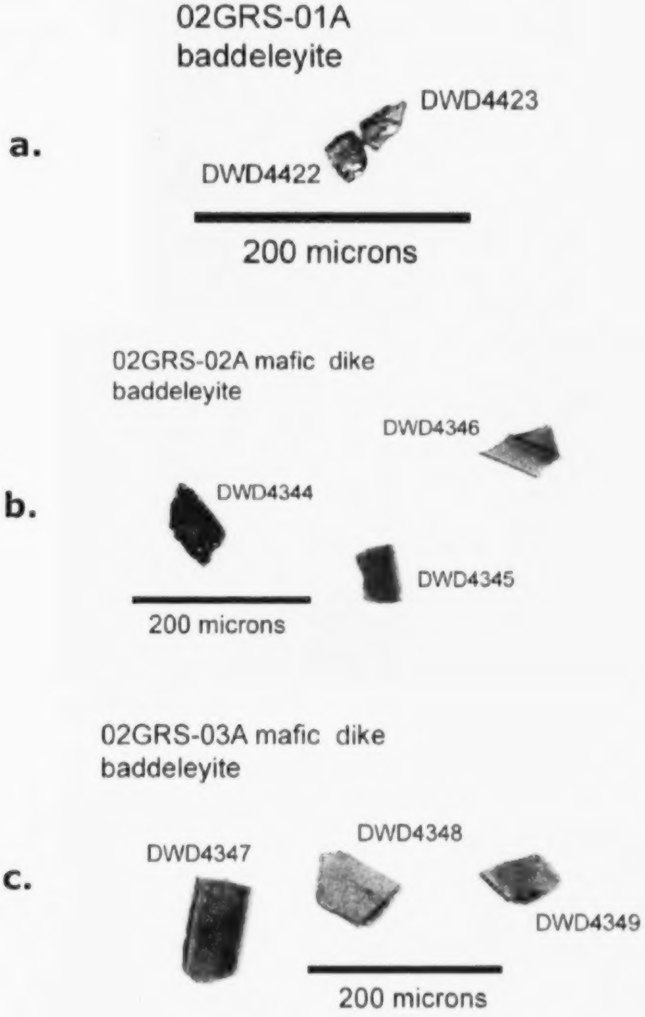
02GRS-01A
baddeleyite
DWD4423
a.
DWD4422
200 microns
02GRS-02A mafic dike
baddeleyite
DWD4346
b.
DWD4344
DWD4345
200 microns
02GRS-03A mafic dike
baddeleyite
DWD4348
DWD4347
c.
DWD4349
200 microns

Figure 12.3. Images of baddeleyite from each of the 3 mafic dikes as listed in Table 12.1.

The 2 north-northeast-striking mafic dikes from east of Lake Nipigon agree in age at 2109 Ma, which indicates that they likely belong to the Marathon dike swarm. Previous work on geochronology and paleomagnetism of the Marathon swarm has shown that reversed and normal Marathon dikes give different ages (2101±2 Ma for reversed and 2121+14/–7 Ma for normal; Hamilton et al. 2002, Buchan, Halls and Mortensen 1996) and different pole positions (Buchan, Halls and Mortensen 1996). The 2109 Ma age of the Nipigon area dikes falls between these ages. The complementary work by Halls and Stott (this volume) is attempting to determine whether the paleomagnetic pole positions of the dikes with established ages are consistent with their age relationships.

The Hillsport dike gives a distinctly older age of 2171±1 Ma, which indicates that it is probably part of the Biscotasing swarm. Previous ages from this swarm are 2167.8±2.2 Ma and 2171.6±1.2 Ma on baddeleyite from 2 dikes (Halls and Davis,) and 2166.7±1.4 Ma on baddeleyite and zircon from another dike (Buchan, Mortensen and Card 1993).

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13. Project Unit 02-036. Geochemistry and Neodymium Isotopic Character of Granitoid Rocks in the Lac Seul Region of the Winnipeg River Subprovince, Northwestern Ontario

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INTRODUCTION

Granitoid rocks can be used as crustal probes to investigate possible interaction with older basement. The interaction with older crust should be reflected in the neodymium (Nd) isotopic character of the granitoid rocks, and hence, even with a lack of uranium–lead (U/Pb) geochronology, Nd isotopes can be used to map the extent, and potentially the age of old crustal basement.

The Winnipeg River Subprovince (*see* Figure 13.1) contains some of the oldest rocks in the Superior Province (3.17 Ga: Corfu 1988). Despite this, Mesoarchean crust is rare and Neoarchean granitoid rocks predominate. Neodymium isotopic studies have been carried out in the west (Kenora area, Tannis Lake and the Lount Lake batholith) and the central part (Cedar Lake) of the Winnipeg River Subprovince, which suggest the widespread occurrence of cryptic Mesoarchean basement (e.g., Henry et al. 2000). In the eastern Winnipeg River Subprovince, to the east of Lac Seul (*see* Figure 13.1), Mesoarchean U/Pb ages (ca. 3.04 Ga) have been determined at scattered localities (e.g., Krogh, Harris and Davis 1976). However, a detailed Nd isotopic study of this part of the Subprovince was lacking and, hence, the extent of Mesoarchean basement was unknown.

Lac Seul provides access to a more than 50 km long east-striking section of a variety of plutonic and gneissic units in the eastern part of the Winnipeg River Subprovince. In this study, we have used major and trace element geochemistry to characterize the granitoid rocks of the Lac Seul area and to examine their petrogenesis. We have measured Nd isotopes to examine crustal recycling and to estimate the age of crustal sources contributing to the granitoid rocks. These data are then used along with published data to reveal the distribution of basement rocks in the Winnipeg River Subprovince.

GEOLOGY AND GEOCHRONOLOGY OF THE WINNIPEG RIVER SUBPROVINCE

The Winnipeg River Subprovince (*see* Figure 13.1) is dominated by gneissic to massive tonalite, gneissic to massive granodiorite, and granite. Minor supracrustal rocks occur as amphibolite and paragneiss enclaves within gneissic and plutonic units (Beakhouse 1991). Metamorphic grade ranges

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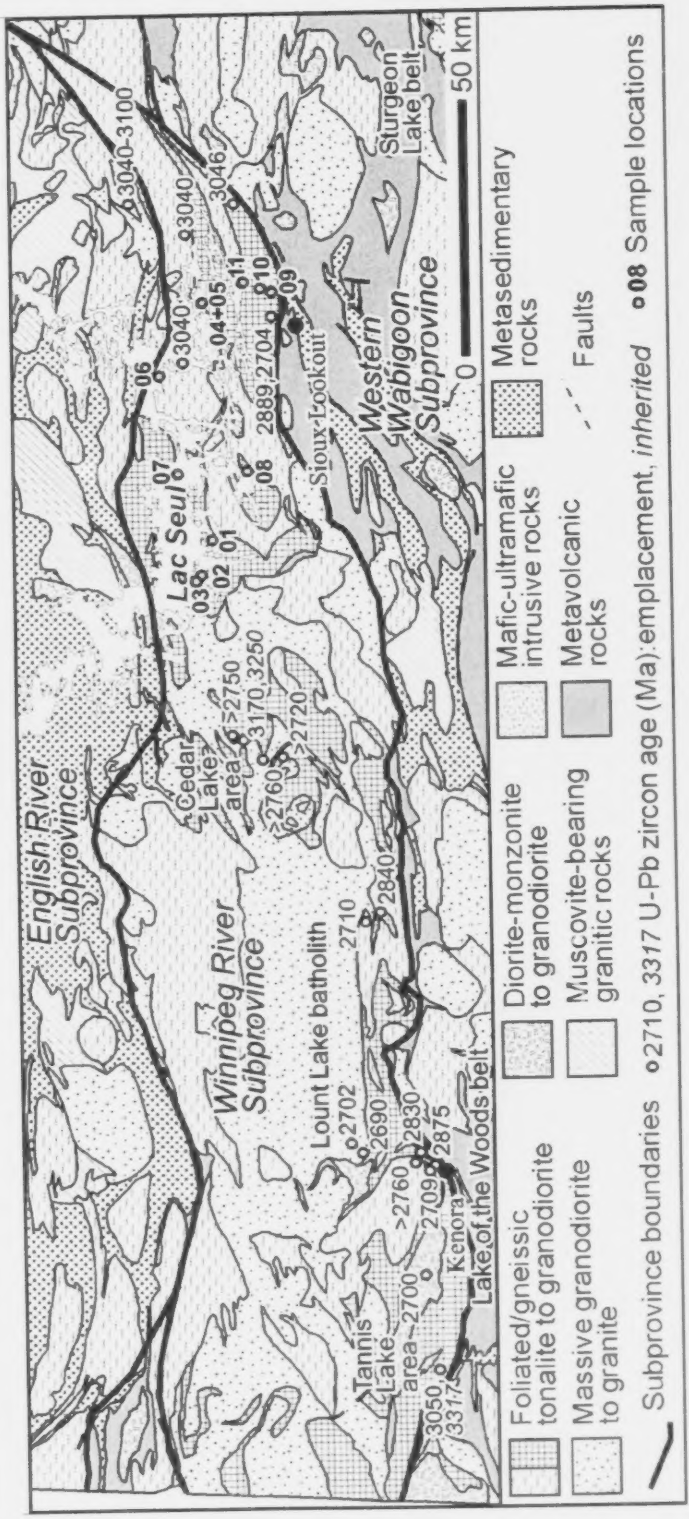
English River Subprovince
Winnipeg River Subprovince
Western Wabigoon Subprovince
Lac Seul
Cedar Lake area
Lount Lake batholith
Tannis Lake area
Kenora
Lake of the Woods belt
Sioux Lookout
Sturgeon Lake belt
3040-3100
3040
3046
3040
06
07
01
02
03
08
-04+05
11
10
09
2889,2704
>2750
3170,3250
2720
2760
>2760
2710
2840
2702
2690
2830
2875
>2760
2709
2700
3050,
3317
0
50 km
Foliated/gneissic tonalite to granodiorite
Massive granodiorite to granite
Diorite-monzonite to granodiorite
Muscovite-bearing granitic rocks
Mafic-ultramafic intrusive rocks
Metavolcanic rocks
Metasedimentary rocks
Faults
Subprovince boundaries
2710, 3317 U-Pb zircon age (Ma): emplacement, inherited
08 Sample locations

Figure 13.1. Simplified geology of the Winnipeg River Subprovince (*modified from* OGS 1991), with the sample locations for this study (01-11) and geochronology *from* Corfu (1988, 1996), Corfu, Stott and Breaks (1995), Beakhouse (1983), Krogh, Harris and Davis (1976), Davis, Sutcliffe and Trowell (1988), Bethune, Helmstaedt and McNicoll (2000), and M. Melnyk (University of Toronto, personal communication, 2001).

from upper amphibolite to local granulite facies (Corfu 1988). Mesoarchean units include tonalite gneiss at Cedar Lake (3.17 Ga: Corfu 1988; 3.25 Ga: M. Melnyk, University of Toronto, personal communication, 2001), massive tonalite at Tannis Lake (3.05 Ga: Davis, Sutcliffe and Trowell 1988; 3.32 Ga: M. Melnyk, University of Toronto, personal communication, 2001) and gneissic tonalites from several locations east of Lac Seul (ca. 3.04 Ga: Krogh, Harris and Davis 1976; Corfu, Stott and Breaks 1995; Bethune, Helmstaedt and McNicoll 2000). Zircon inheritance as old as 3.39 Ga has also been found in tonalite gneiss at Cedar Lake (Mueller 1991). Younger tonalite gneiss phases have ages of 2.88, 2.84 and 2.83 Ga (Corfu 1988; Beakhouse 1983), along with granodiorite to granite sheets (2.89 to 2.88 Ga: Corfu 1988, 1996; Cruden et al. 1997). Neoarchean tonalites and granodiorites have ages of 2.72 to 2.70 Ga with late granites intruded at 2.69 Ga (Cruden et al. 1997; 1998; Beakhouse 1983; Corfu 1988, 1996).

PREVIOUS NEODYMIUM ISOTOPIC WORK

Isotopic data from the oldest dated Mesoarchean rocks in the Winnipeg River Subprovince at Cedar Lake and Tannis Lake show Nd model ages of 3.26 Ga and 3.44 to 3.39 Ga, respectively, suggesting that they were isolated from the depleted mantle reservoir at circa 3.4 to 3.3 Ga. This indicates that the original crust of the Winnipeg River Subprovince was likely as old as 3.4 Ga (Henry et al. 2000). This is consistent with zircon inheritance data suggesting reworking of 3.39 billion-year-old crust during tonalite plutonism at Cedar Lake 3.17 billion years ago (Mueller 1991). From the eastern end of the Winnipeg River Subprovince (eastern Lac Seul, *see* Figure 13.1), one sample of tonalite gneiss that may be as old as 3.04 Ga has a Nd model age of 3.26 Ga (Henry et al. 2000).

Somewhat younger suites of tonalite (ca. 2.88 to 2.83 Ga) and tonalite gneiss from Kenora and Daniels Lake (west-central Winnipeg River Subprovince) have Nd model ages of 3.04 to 2.94 Ga reflecting contamination by, or melting of, crust older that 3.0 Ga (Henry et al. 2000). Granite-granodiorite (ca. 2.76 Ga) from Cedar Lake has Nd model ages of 3.22 to 3.05 Ga and, from north of Kenora, a model age of 2.81 Ga, suggesting both the addition of juvenile crust and recycling of some of the oldest crust (Henry et al. 2000). Isotopic data from the granodioritic to granitic Lount Lake batholith (2.70 Ga; Nd model ages of 3.08 to 2.86 Ga) indicate formation of this extremely large body by intracrustal melting of tonalite (Beakhouse and McNutt 1991) (*see* Figure 13.1). Similarly, granodiorites (2.71 to 2.69 Ga) from various locations around Kenora have Nd model ages of 3.09 to 2.88 Ga also suggesting recycling of older crust (Henry et al. 2000). These data suggest the occurrence of variably reworked, much older crust, throughout much of the Winnipeg River Subprovince.

METHODOLOGY

The Lac Seul area was targeted for sampling for whole rock geochemistry and Nd isotopic analyses. Eleven samples were collected. Based on field identification, these samples were 4 tonalite gneisses, 2 foliated tonalites (one a metre-scale enclave within foliated granodiorite), 1 foliated to gneissic tonalite, 1 gneissic tonalite to granodiorite, 2 granodiorite gneisses and 1 foliated granodiorite. Large samples were collected (10 to 20 kg) with the view of also conducting U/Pb geochronology on selected samples. From these large samples, 1 to 2 kg of representative material were crushed and powdered for geochemical and Nd isotopic analysis. Major and trace elements were analyzed at the Geoscience Laboratories, Sudbury. Major elements were analyzed by X-ray fluorescence and trace elements by inductively coupled plasma mass spectrometry (ICP–MS). Nd isotopes were measured in the thermal ionization mass spectrometry (TIMS) laboratory at the School of Geography and Geology, McMaster University, Hamilton, using the method of Dickin (1998). The data are presented in Table 13.1, along with calculated epsilon Nd (ε_{Nd}) values (see below for discussion of ages used), and neodymium-depleted mantle model ages (model of DePaolo 1981).

Table 13.1. Samarium-neodymium isotopic data for granitoid rocks from the Lac Seul area.

Sample	Field-based Lithology	Measured ^{143}Nd/^{144}Nd	Measured ^{147}Sm/^{144}Nd	Nd (ppm)	Sm (ppm)	Age* (Ga)	Epsilon Nd (T)	DePaolo T_{DM} (Ga)
01KYT-01	Biotite tonalite gneiss	0.511077	0.1098	9.32	1.69	2.889	+1.90	2.912
01KYT-02	Foliated hornblende tonalite	0.511482	0.1502	12.60	3.13	3.040	–4.37	3.898
01KYT-03	Hornblende biotite tonalite gneiss	0.510813	0.1051	19.27	3.35	3.040	+0.28	3.170
01KYT-04	Foliated granodiorite	0.510406	0.0944	13.20	2.06	2.889	–5.52	3.420
01KYT-05	Foliated to gneissic biotite tonalite	0.510936	0.1184	17.29	3.39	3.040	–2.55	3.434
01KYT-06	Granodiorite gneiss	0.510288	0.0847	22.10	3.09	2.889	–4.20	3.296
01KYT-07	Gneissic tonalite to granodiorite	0.510509	0.0772	9.57	1.22	2.889	+2.95	2.850
01KYT-08	Biotite granodiorite gneiss	0.510110	0.0681	24.89	2.81	2.889	–1.48	3.099
01KYT-09	Foliated biotite tonalite enclave	0.510718	0.0911	28.05	4.23	2.889	+1.85	2.915
01KYT-10	Biotite tonalite gneiss	0.510684	0.0895	18.97	2.81	2.889	+1.78	2.920
01KYT-11	Biotite tonalite gneiss	0.510600	0.0833	17.33	2.39	2.889	+2.45	2.878

*Age estimated from field relationships and the age of nearby units

The age of the units are unknown, but, in eastern Lac Seul, an age of 3.040 Ga has been obtained from gneissic to foliated tonalite and an age of 2.889 Ga from granodiorite-granite (Corfu 1988, 1996; Corfu, Stott and Breaks 1995). On this basis, the granodioritic units were assigned an age of 2.889 Ga and the tonalitic units were assigned an age of 2.889 or 3.040 Ga depending on their structural complexity and relationship with adjacent units. Some tonalitic units that were thought to belong to the older suite were later assigned younger ages (for calculation of epsilon Nd) owing to their Nd model ages of less than 2.95 Ga.

RESULTS

Major Elements

The granitoid rocks are classified on a CIPW normative albite-anorthite-orthoclase diagram in Figure 13.2a. The majority of samples plot as tonalite, but the granodioritic rocks (field-based name) plot in the granite field. On an alkali–FeO–MgO (AFM) diagram (Figure 13.2b), all the samples are calc-alkaline. In terms of SiO$_2$ and Al$_2$O$_3$ (Figure 13.2c), the true tonalitic rocks have high Al$_2$O$_3$ (16 to 18 weight %) and 63 to 68 weight % SiO$_2$. The granodioritic rocks have 13 to 15 weight % Al$_2$O$_3$ and 72 to 74 weight % SiO$_2$, and one sample is transitional between these 2 groups. In terms of K$_2$O (classification of Le Maitre 1989), 2 of the granodioritic rock samples contain high levels of potassium, whereas the rest of the samples possess medium amounts of potassium (Figure 13.2d).

Trace Elements

Primitive mantle normalized multi-element diagrams are shown in Figure 13.3 (a to e) with the samples grouped according to rock type and/or area. All the samples are enriched in the light rare earth elements (LREE) with the 2 granodiorite gneiss samples having the highest (La/Yb)$_N$ at 56 and 109. The other samples all have (La/Yb)$_N$ ratios ranging from 20 to 52, with the exception of 2 tonalitic samples

(02 and 05, with much higher Yb contents than the other rocks), which have low $(La/Yb)_N$ values of 4.3 and 12.4, respectively. General features of the multi-element profiles for all samples are

1. high abundances of the large-ion lithophile elements (LILE) Cs, Rb, Ba and K, and generally high Th and U (except for sample 07);
2. fractionated heavy REE profiles consistent with partial melting in the presence of garnet;
3. negative Nb and Ti anomalies (with the exception of sample 04), which may be inherited from the source, or represent titanium-magnetite fractionation; and
4. a lack of an Eu anomaly, indicating a lack of potassium feldspar fractionation.

Strontium values and Sr/Y can be important in studying the petrogenesis of tonalitic rocks. Strontium values are high in all the tonalitic samples (327 to 818 ppm) and Sr/Y ratios range from 53 to 350, with the exception of samples 02 and 05 which have high Y and low Sr/Y ratios of 16 and 22, respectively.

Neodymium Isotopes

Epsilon Nd values are plotted against time in Figure 13.3f, along with previously published isotopic data from the Winnipeg River Subprovince. Previously published data from granodioritic to granitic rocks show a range of epsilon Nd values from 0 to –3 at circa 2.7 Ga. Previously published data from tonalitic samples show a greater spread of around +1.5 to –3.5, mostly from Mesoarchean rocks (*see* Figure 3f). The new data presented here increase that range further, with 3 samples (2 granodiorites and 1 tonalite)

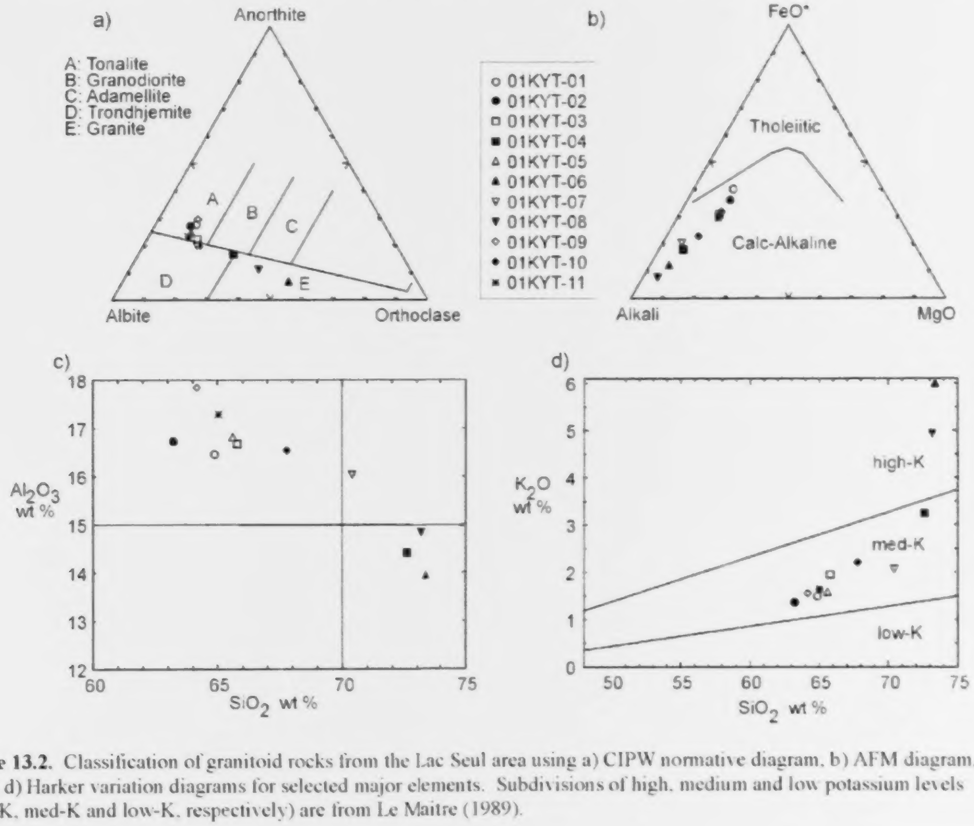

Figure 13.2. Classification of granitoid rocks from the Lac Seul area using a) CIPW normative diagram, b) AFM diagram, c) and d) Harker variation diagrams for selected major elements. Subdivisions of high, medium and low potassium levels (high-K, med-K and low-K, respectively) are from Le Maitre (1989).

having very low epsilon Nd values of –4 to –6 and several samples (all tonalitic) having relatively juvenile values of +1 to +3 (at 2.9 Ga). Due to the uncertainty in age of these samples, the epsilon Nd values (that have been calculated at assigned ages) may be in error. If this is the case, the samples would generally move parallel to the crustal evolution lines shown on Figure 13.3f, to higher epsilon Nd values if the samples are older than shown, or lower epsilon Nd values if the samples are younger than shown.

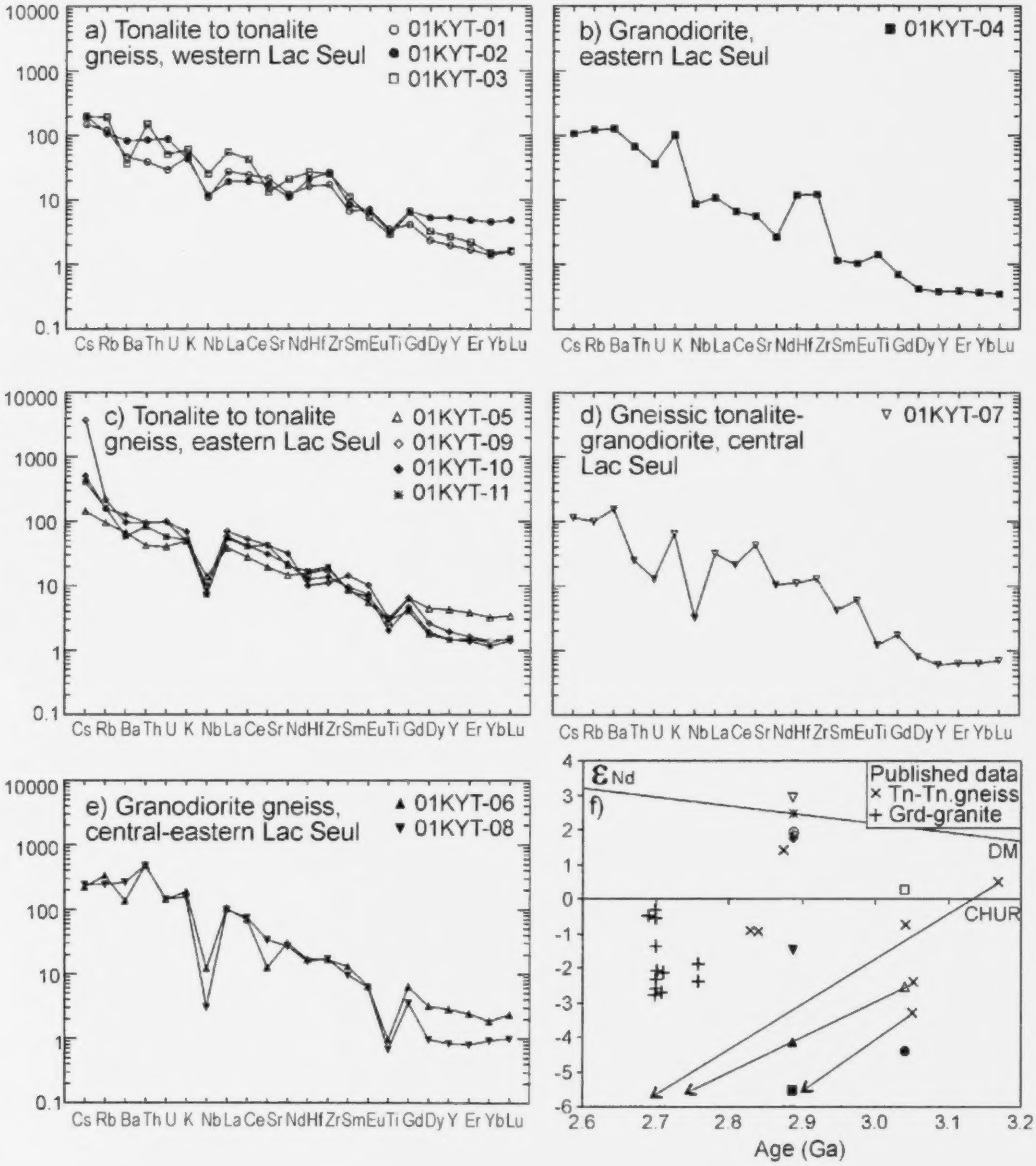

Figure 13.3. a) to e) Primitive mantle normalized multi-element diagrams (normalizing values of Sun and McDonough, 1989). f) Epsilon Nd versus age diagram for rocks from the Winnipeg River Subprovince using previously published data *from* Beakhouse and McNutt (1991), Henry et al. (2000), and Beakhouse and Creaser (2002); other symbols are the same as in spider diagrams 13.3a to 13.3e, crustal evolution lines (arrows) are shown for the oldest crust in the Winnipeg River Subprovince; abbreviations: DM, depleted mantle; CHUR, chondritic uniform reservoir; Tn, tonalite; Grd, granodiorite (foliated or gneissic).

Therefore, the cluster of juvenile samples plotted at 2.9 Ga, could indeed represent juvenile magmatism at circa 2.9 Ga, or, if the rocks were 2.7 billion years old, they would have slightly negative epsilon Nd values at 2.7 Ga, which would be similar to other rocks from the Winnipeg River Subprovince and suggest reworking of Mesoarchean crust. Two other tonalitic samples (03 and 05) have intermediate (+0.3 and –2.6) epsilon Nd values similar to those observed for rocks from Tannis Lake, Cedar Lake and east of Lac Seul. The Nd model ages of these 2 samples are 3.17 and 3.43 Ga, respectively. The granodiorite samples (06 and 04) with the very low epsilon Nd values also have extremely old Nd model ages of 3.3 to 3.42 Ga. These model ages are similar to the oldest Nd model ages from the Winnipeg River Subprovince, that is, 3.44 Ga from 3.05 billion-year-old tonalitic rocks in the Tannis Lake area (Henry et al. 2000).

DISCUSSION

The tonalitic and granodioritic rocks of the Lac Seul area are typical of the Archean tonalite-trondhjemite-granodiorite suite (TTG) in terms of major and trace element geochemistry (e.g., Drummond and Defant 1990). Such tonalitic rocks are generally considered to have been generated by partial melting of garnet amphibolite (metamorphosed basaltic crust), either in a subduction zone or from underplated mafic material (Martin 1986; Windley 1995). The granodioritic rocks may have formed by fractional crystallization of tonalitic magmas, or by partial melting of tonalitic crust.

The Nd isotope data suggest the occurrence of Mesoarchean crust throughout the Lac Seul area as shown by Nd model ages of older than 3.0 Ga occurring in the east, centre and west of Lac Seul (*see* Table 13.1). The oldest model ages (3.42 to 3.43 Ga) are from a granodiorite and tonalite sample from the same outcrop in eastern Lac Seul (samples 04 and 05). These model ages, and similar ages from Tannis Lake (in the western Winnipeg River Subprovince), suggest that the original crust in this area was at least 3.4 Ga, and that this crust was widespread, occurring both in the eastern and western parts of the Winnipeg River Subprovince.

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14. Project Unit 03-008. Fertile Peraluminous Granites and Related Rare-Element Pegmatite Mineralization, Barbara–Gathering–Barbaro Lakes Area, North-Central Ontario

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INTRODUCTION

The Georgia Lake pegmatite field (Figures 14.1 and 14.2), as defined by Pye (1965) and Mulligan (1965), represents the largest concentration of rare-element mineralization in the Superior Province of Ontario. The vast majority of 38 rare-element occurrences and 10 spodumene pegmatite deposits, the latter with a total resource of 11.7 million tons averaging 1.14% Li_2O, were discovered during the lithium rush of the 1950s (Pye 1956).

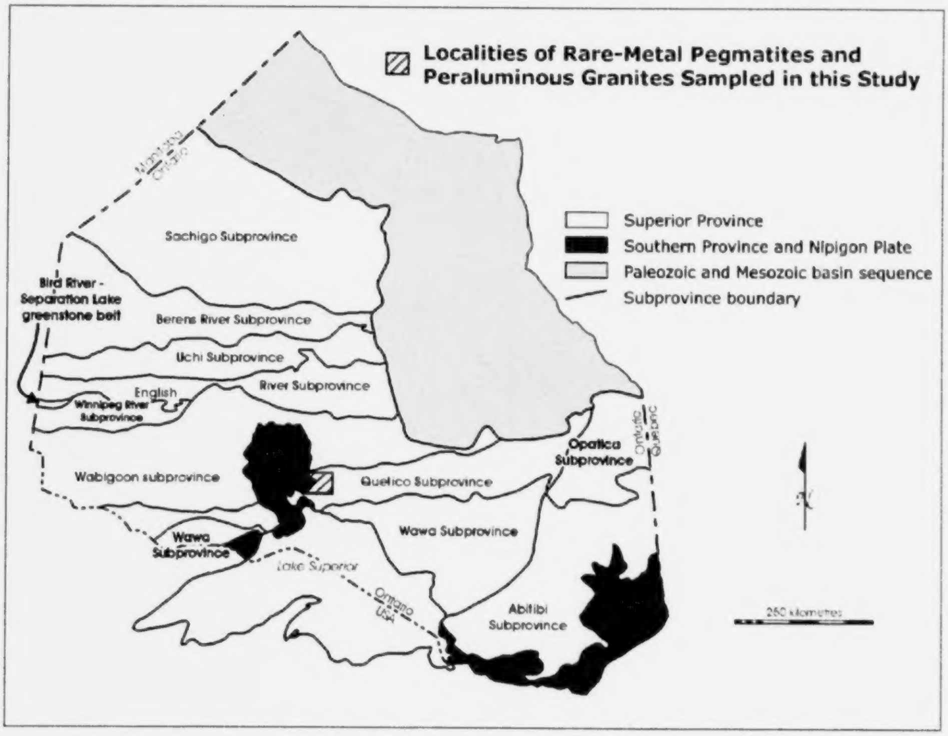
▨ Localities of Rare-Metal Pegmatites and Peraluminous Granites Sampled in this Study
Superior Province
Southern Province and Nipigon Plate
Paleozoic and Mesozoic basin sequence
Subprovince boundary
Manitoba
Ontario
Sachigo Subprovince
Bird River - Separation Lake greenstone belt
Berens River Subprovince
Uchi Subprovince
English
River Subprovince
Winnipeg River Subprovince
Wabigoon subprovince
Quetico Subprovince
Opatica Subprovince
Ontario
Quebec
Wawa Subprovince
Wawa Subprovince
Lake Superior
Ontario
USA
Abitibi Subprovince
250 kilometres

Figure 14.1. Location of peraluminous pegmatitic granite masses and rare-element pegmatite mineralization examined in this study.

Summary of Field Work and Other Activities 2003, Ontario Geological Survey, Open File Report 6120, p.14-1 to 14-13.

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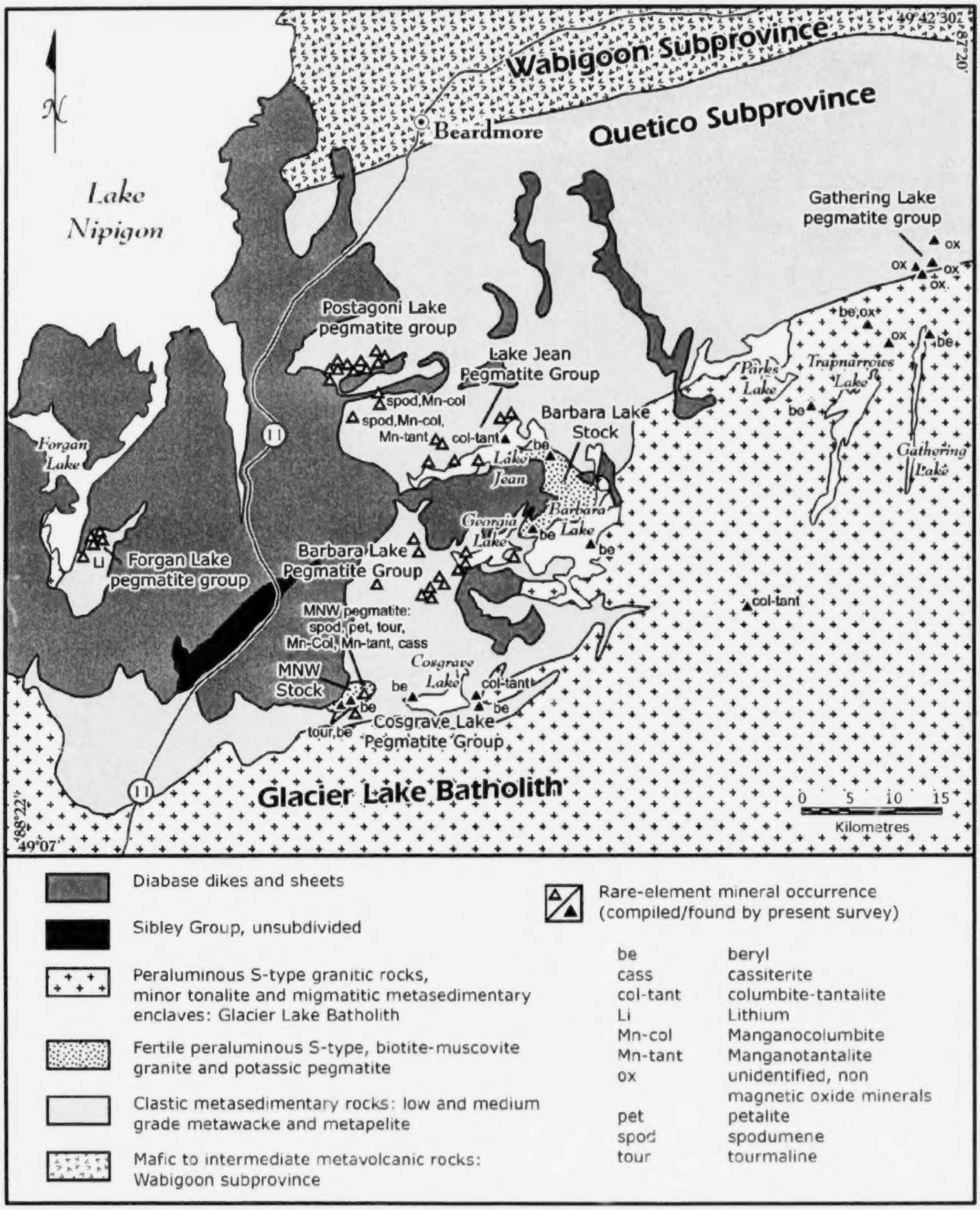
49°42'30"
87°20'
Wabigoon Subprovince
Quetico Subprovince
Beardmore
Lake Nipigon
N
Gathering Lake pegmatite group
ox
ox
ox
ox
be,ox
ox
be
Trapnarrows Lake
Parks Lake
be
Gathering Lake
Postagoni Lake pegmatite group
spod,Mn-col
spod,Mn-col, Mn-tant
Lake Jean Pegmatite Group
col-tant
Barbara Lake Stock
be
Lake Jean
11
Forgan Lake
Georgia Lake
Barbara Lake
be
be
Li
Forgan Lake pegmatite group
Barbara Lake Pegmatite Group
col-tant
MNW pegmatite: spod, pet, tour, Mn-Col, Mn-tant, cass
MNW Stock
Cosgrave Lake
be
col-tant
be
be
tour,be
Cosgrave Lake Pegmatite Group
Glacier Lake Batholith
11
0 5 10 15
Kilometres
88°22'
49°07'
Diabase dikes and sheets
Sibley Group, unsubdivided
Peraluminous S-type granitic rocks, minor tonalite and migmatitic metasedimentary enclaves: Glacier Lake Batholith
Fertile peraluminous S-type, biotite-muscovite granite and potassic pegmatite
Clastic metasedimentary rocks: low and medium grade metawacke and metapelite
Mafic to intermediate metavolcanic rocks: Wabigoon subprovince
Rare-element mineral occurrence (compiled/found by present survey)
be beryl
cass cassiterite
col-tant columbite-tantalite
Li Lithium
Mn-col Manganocolumbite
Mn-tant Manganotantalite
ox unidentified, non magnetic oxide minerals
pet petalite
spod spodumene
tour tourmaline

Figure 14.2. General geological location of rare-element mineralization in the Georgia Lake area, Quetico Subprovince.

This 32 by 37 km pegmatite field, entirely hosted within the clastic metasedimentary context of medium metamorphic grade of the central Quetico Subprovince, is populated by rare-element pegmatites of 4 distinct types in reference to the classification of Černý (1991):

- beryl-type
- albite-spodumene-type
- complex-type, petalite-subtype
- albite-type

Various petrographic, petrochemical and mineral chemical features of the rare-element pegmatites and related fertile, peraluminous granites were documented by Milne (1962), Pye (1965), Breaks (1980), Kissin and Zayachkivsky (1985) and Kissin, Zayachkivsky and Branscombe (1986). Breaks (1980, p.7-8) proposed that the complex-type, petalite-subtype MNW pegmatite was hosted in its parent granite, named the MNW stock. The MNW pegmatite is named from the initials of the 3 men, John Moschuk, T. Neborac and Murray Wilson, who discovered and staked it in May 1955 (Pye 1965). The work of Pye (1965, p.53) and Kissin, Zayachkivsky and Branscombe (1986) established the fertile status of this pluton and others in the area (Barbara Lake stock, pegmatitic granites in the Barbara Lake area and parts of the Glacier Lake batholith (McCrank, Misiura and Brown 1981; *see* Figure 14.2).

The main purpose of the current investigation is to evaluate various peripheral areas of the Georgia Lake pegmatite field for further fertile, peraluminous granites and related rare-element mineralization. These include the Barbara–Gathering–Barbaro lakes area (Figure 14.3) that lies east from the edge of Pye's Map 2056 (Pye 1965) and which has never been mapped, the Helen Lake section along Highway 11 and Highway 585 north of Nipigon. The second purpose of this survey is to expand the geochemical-mineralogical database of Kissin, Zayachkivsky and Branscombe (1986) by examining the known fertile granites and a representative suite of the known rare-element pegmatite types.

The main impact of the present survey has been three-fold:

- documentation of widespread peraluminous, S-type granite and pegmatitic granite in the Barbara–Gathering–Barbaro lakes area with presence of local rare-element mineralization
- discovery of a new pegmatite group (Gathering Lake pegmatite group: *see* Figure 14.2) that contains beryl-type and albite-type pegmatites
- discovery of 17 new rare-element mineral occurrences in the Georgia Lake pegmatite field

SAMPLING PROCEDURE

Figure 14.3 indicates the locations of all sample sites during this study. UTM co-ordinates for the various sites are included in the text of this report and are in NAD 83. Samples from the majority of the sites have been submitted to the Geoscience Laboratories, Geoservices Centre, Sudbury as bulk rock samples. This collection includes 237 bulk rock samples, and various rare-element pegmatite indicator minerals [potassium feldspar (77 samples) and muscovite (49 samples)] in addition to numerous minerals selected for electron microprobe work at the OGS and The Open University (tantalum-niobium-bearing oxide minerals, garnet, tourmaline, apatite, phosphate minerals and beryl). The bulk rock sampling in particular has provided a cross-section of 40 km across the granitic part of the Quetico Subprovince as accessed principally along John Ahl Road (*see* Figure 14.3). Between 2 and 10 kg of bulk rock material were collected of each sample with sample weight dependent upon grain size.

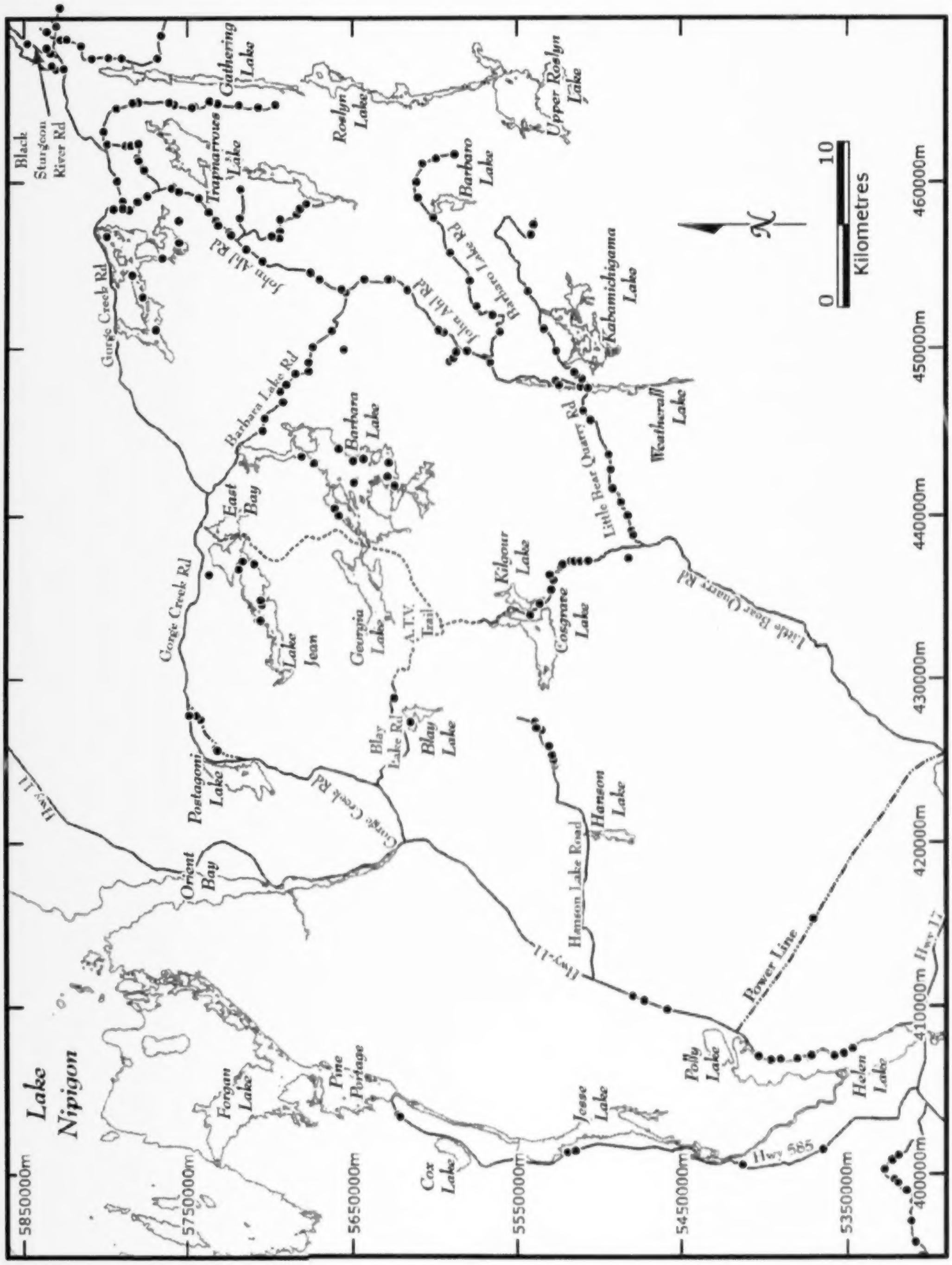
Lake Nipigon
Forgan Lake
Pine Portage
Cox Lake
Jesse Lake
Polly Lake
Helen Lake
Hwy 585
Hwy 17
Power Line
Hwy 11
Hanson Lake Road
Hanson Lake
Orient Bay
Postagoni Lake
Gorge Creek Rd
Blay Lake Rd
Blay Lake
Lake Jean
Georgia Lake
A.T.V. Trail
Cosgrave Lake
Kilgour Lake
Little Bear Quarry Rd
East Bay
Barbara Lake
Barbara Lake Rd
Weatherall Lake
John Ahl Rd
Barbaro Lake Rd
Barbaro Lake
Kabamichigama Lake
Black Sturgeon River Rd
Trapnarrows Lake
Gathering Lake
Roslyn Lake
Upper Roslyn Lake
N
0
10
Kilometres
5850000m
5750000m
5650000m
5550000m
5450000m
5350000m
400000m
410000m
420000m
430000m
440000m
450000m
460000m

Figure 14.3. Location of all sample sites visited during this study.

FERTILE GRANITIC PLUTONS WITHIN GEORGIA LAKE AREA

Two distinct peraluminous granite plutons occur entirely within medium-grade clastic metasedimentary host rocks of the Georgia Lake area: the MNW Stock (Breaks 1980) and the Barbara Lake stock (Kissin, Zayachkivsky and Branscombe 1986, p.66). These plutons consist of virtually identical, grey, medium-grained, generally homogeneous, biotite-muscovite and muscovite-biotite granite and granodiorite. The full extent of both plutons is unknown due to overlapping diabase sheets. Dikes and gradational, consanguineous masses of muscovite-, tourmaline-muscovite- and biotite-tourmaline-muscovite potassic pegmatite occur in both plutons. These units may contain sporadic euhedral crystals of beryl as at localities 03-FWB-07 (UTM: Zone 16, 425332E, 5452806N) and 03-FWB-10 (UTM: Zone 16, 425881E, 5452656N) in the MNW stock and at locality 03-JBS-91 (UTM: Zone 16, 440504E, 5471006N) in the Barbara Lake stock. Several outcrops of the MNW stock revealed a deep pink to bright orange fresh surface possibly due to oxidation effects of fracture-controlled hydrothermal fluids. The muscovite potassic pegmatite unit in the MNW stock contains sporadic masses, up to 3 by 5 cm in size, of a dark green soft mineral associated with blue apatite. The dark green mineral was determined by X-ray diffraction work to be alluaudite. A similar mineral was noted in the MNW stock and in a muscovite-blocky potassium feldspar-quartz pegmatite situated at locality 03-FWB-13 (UTM: Zone 16, 427230E, 5453911N) about 100 m northeast of the MNW pegmatite.

The Glacier Lake batholith (McCrank, Misiura and Brown 1981) is a large mass of medium- to coarse-grained granite and pegmatitic granite situated immediately south of the northern metasedimentary part of the Quetico Subprovince (*see* Figure 14.2). This survey has traced its extent for a minimum of 50 km, from Highway 11 to Barbaro Lake. A grey, medium- to coarse-grained biotite and muscovite-biotite granite is the dominant rock type. This rock is massive to locally weakly foliated due to 1 to 2 cm thick, shallowly lineated veins of fibrolite, muscovite and quartz that appear to have formed during aluminous hydrothermal alteration controlled by late shearing. Gradation into consanguineous pods of tourmaline-muscovite potassic pegmatite up to 1 m in diameter is prevalent at localities 03-FWB-02 (UTM: Zone 16, 409911E, 5445897N) near Cosgrave Lake; on Highway 11 at locality 03-FWB-01 (UTM: Zone 16, 437290E, 5448243N); and along the Barbaro Lake Road as at 03-FWB-94 (UTM: Zone 16, 454141E, 5457843N). The 03-FWB-02 locality contains local pods of tourmaline-biotite-muscovite potassic pegmatite that in some cases reveal zonation marked by a black tourmaline-rich core and enveloping leucocratic, white feldspar-rich material.

Pye (1965, p.53) undertook the first lithogeochemical survey for rare-elements in the Georgia Lake area. Many lithium anomalies in the 100 to 400 ppm range were documented as in the Barbara Lake stock (5 samples with 150 to 400 ppm); the MNW stock (5 of 6 samples with 100 ppm); a granite mass in the Rim Lake area; and locally in the Glacier Lake batholith (4 samples in the 150 to 200 ppm range).

GRANITIC TERRANE EAST OF BARBARA LAKE

This previously unmapped area dominantly consists of biotite, cordierite-biotite, muscovite-biotite and biotite-muscovite peraluminous granite and related pegmatitic granites. The latter were divided utilizing the classification of Černý and Meintzer (1988). Enclaves of layered metasedimentary migmatite up to 2 km in width and of undefined strike length were encountered on John Ahl Road as exemplified at locality 03-FWB-47 (UTM: Zone 16, 449871E, 5458009N). Minor amounts of tonalitic rocks occur throughout the area.

Less fractionated rocks (biotite granite, biotite potassic pegmatite and greater abundance of enclaves of metasedimentary migmatite) predominate in the south along the Little Bear Quarry Road from

Weatherall Lake to the east end of the road. Muscovite-bearing, peraluminous rocks, such as granite, pegmatitic leucogranite, potassic pegmatite and layered aplites, were encountered northward along John Ahl Road to Parks Lake.

Near Weatherall Lake, at locality 03-FWB-45 (UTM: Zone 16, 448074E, 5452632N), an extensive outcrop area exemplifies the biotite granite-dominant area. Here, medium- to coarse-grained biotite and cordierite-biotite granite contains segregations of muscovite-biotite potassic pegmatite and quartz-rich pods. These pods are completely gradational into the host biotite and cordierite-biotite granite. The pods, up to 50 cm by 2 m in size, contain blocky potassium feldspar, rose quartz and black tourmaline in prisms up to 2.5 by 12 cm in size or in graphic intergrowths with quartz. The granite also contains a wispy foliation defined by 1 to 2 cm thick veins of shallowly lineated, yellow green muscovite and fibrolite.

To the north, along John Ahl Road, muscovite-biotite and biotite-muscovite, pegmatitic leucogranite masses become increasingly abundant as at locality 03-FWB-52 (UTM: Zone 16, 451153E, 5459747N). This glacially polished exposure reveals tourmaline-biotite-muscovite pegmatitic leucogranite with characteristic and widespread megacrysts of graphic quartz-potassium feldspar up to 1 m in diameter. Graphic intergrowths of quartz-tourmaline and quartz-garnet also occur. Fractionation into patches and small tabular zones of muscovite-tourmaline potassic pegmatite is notable with black tourmaline masses up to 7 by 13 cm and silver muscovite books up to 3 cm thick and 20 cm in length. Quartz-rich patches with suspended crystals of euhedral to subhedral blocky potassium feldspar are also a common occurrence in the pegmatitic leucogranites as is the case at locality 03-FWB-52. Faint brown to green beryl up to 3 cm in diameter may occur in these quartz patches as at locality 03-FWB-71 (UTM: Zone 16, 459139E, 5474345N) on John Ahl Road.

Several other features characterize the pegmatitic leucogranite masses:

- layering with muscovite-garnet fine-grained leucogranite up to 40 cm in thickness, as at 03-FWB-53 (UTM: Zone 16, 453580E, 5461624N); and
- grey, plumose, irregular intergrowths composed of fine-grained, muscovite-quartz up to 40 by 65 cm in size, that comprise up to 10 percent of the rock.

Muscovite-bearing, medium- to coarse-grained granite becomes a widespread and dominant rock type at locality 03-FWB-60 (UTM: Zone 16, 456906E, 547238N) and northward to the metasedimentary dominant part of the Quetico Subprovince near the junction of John Ahl and Gorge Creek roads (*see* Figure 14.3). Many outcrops along the Trapnarrows Lake road (*see* Figure 14.3) reveal massive, medium- to coarse-grained, biotite-muscovite granite grading into masses and veins of muscovite potassic pegmatite. Quartz-rich patches occur sporadically in the potassic pegmatite and contain coarse, silver muscovite books and blocky potassium feldspar up to 0.5 by 1 m in size.

Outcrops along the Gathering Lake road (west side of Gathering Lake) display a transition from fertile granite to albite-type pegmatite dikes (*see* Figure 14.3). From the southern tip of Gathering Lake northward, the granitic rocks become progressively more fractionated: biotite granite to muscovite potassic pegmatite to interlayered biotite potassic pegmatite + garnet aplite to albite-type pegmatite dikes. The change in mineralogy from the biotite granite to the albite-type pegmatites can be used as a prospecting tool. The mica changes from biotite-dominant to muscovite-dominant, and the feldspar changes from potassium feldspar-dominant to albite-dominant. Thus, the granitic rocks close to the albite-type pegmatites contain dominant muscovite and albite.

The muscovite potassic pegmatite at locality 03-JBS-73 (UTM: Zone 16, 464795E, 5475843N) consists of coarse-grained, graphic, yellow potassium feldspar and plumose muscovite fans radiating from muscovite blades up to 25 cm long. Plumose muscovite fans (graphic intergrowths of muscovite and quartz) in muscovite potassic pegmatite are particularly large and abundant at locality 03-JBS-87 (UTM: Zone 16, 461416E, 5477976N). The most spectacular outcrops of alternating layers of garnet-muscovite aplite and bladed biotite potassic pegmatite occurs at localities 03-JBS-71 (UTM: Zone 16, 464902E, 5478355N) and 03-JBS-72 (UTM: Zone 16, 464945E, 5478022N). These pegmatitic dikes intrude white, fine-grained biotite granite.

PEGMATITE GROUPING

The Georgia Lake pegmatite field was initially subdivided by Milne (1962) and subsequently modified by Kissin and Zayachkivsky (1985) into northern, central and southern pegmatite groups. The current work indicates that a six-fold division is merited on the basis of new data (*see* Figure 14.2):

- Postagoni River group
- Lake Jean pegmatite group
- Barbara Lake pegmatite group
- Forgan Lake pegmatite group
- Cosgrave Lake pegmatite group
- Gathering Lake pegmatite group

The first 4 groups are dominated by pegmatites of the albite-spodumene-type with its characteristic orientation of green spodumene normal to pegmatite-host rock contacts and layering of internal units (Černý 1989, 1991). The Cosgrave Lake pegmatite group is dominated by beryl-type pegmatites with one petalite-subtype pegmatite. The Gathering Lake pegmatite group is dominated by albite-type pegmatites. Representative pegmatites of each group were examined except for the Forgan Lake and Barbara Lake pegmatite groups that were not included in the present study.

Postagoni Lake Pegmatite Group

Several albite-spodumene-type pegmatites distributed in a 4 by 6 km area were examined including McVittie, Brink, Dunning and Nama Creek pegmatites (Pye 1965), principally to document the oxide mineralogy.

Lake Jean Pegmatite Group

The Foster, Giles and Trans pegmatites were also briefly examined for oxide minerals that were found in these albite-spodumene-type pegmatites. An apparent barren pegmatite dike mapped by Pye (1965) at 03-JBS-94 (UTM: Zone 16, 436668E, 5471902N), on the north shore of Lake Jean, contains oxide minerals associated with an aplite border zone.

Cosgrave Lake Pegmatite Group

This group is distributed over a 3 by 11 km area and mainly comprises beryl-type pegmatites that occur within and proximal to the MNW stock (*see* Figure 14.2). Five new beryl-type pegmatites were documented by the present survey (*see* Figure 14.2). These new pegmatites and the Swanson beryl pegmatite (Pye 1965) and complex-type, petalite subtype MNW pegmatite, define this group.

MNW PEGMATITE

This internally zoned, complex-type pegmatite represents the first documented petalite locality in Ontario (Breaks 1980). It is also a rare example of a rare-element pegmatite entirely hosted in its parent granite, one of two such pegmatites in the Superior Province of Ontario (see also Lowther pegmatite: Breaks, Selway and Tindle 2003, p.104).

The following internal zones are distinguishable:

- metasomatic reaction zone in host-rocks
- wall zone of tourmaline-rich aplite
- intermediate zone of tourmaline-muscovite-albite-quartz
- cleavelandite-rich replacement zone along boundary of core zone
- potassium feldspar-quartz-petalite core zone

The metasomatic reaction zone comprises a white, 2 to 3 cm thick, strip that encloses the entire pegmatite. It marks a zone where the biotite-muscovite granite host rocks of the MNW pegmatite is completely devoid of biotite and muscovite and where the feldspars appear to have been albitized.

A black tourmaline-rich, aplite wall zone, 10 to 20 cm thick, occurs inwards from the metasomatic zone. Minor amounts of red fluorapatite and megacrysts of quartz also occur in the wall zone.

The 1 to 6 m thick intermediate zone is quartz-rich (60 volume %) and contains yellow green muscovite, white albite and dark green tourmaline. Small patches of sugary aplite up to 10 cm in width locally replace this unit.

The cleavelandite-rich replacement zone occurs continuously along the margins of the core zone and is 30 cm to 1.5 m thick. The rock comprises a semi-circular contact between replacement zone and core zone composed dominantly of radiating fans of light blue to pink cleavelandite. Textural details noted by Breaks (1980) indicate that the cleavelandite zone is actually a late stage albitization "front" as revealed by partial replacement of petalite by cleavelandite, serration and penetration of potassium feldspar, beryl and quartz by cleavelandite in the adjacent quartz-petalite core. Phosphate minerals, complexly intergrown with the cleavelandite, are locally abundant and consist of fluorapatite. Green tourmaline, faint green "ragged" mica minerals, white beryl and local masses of manganocolumbite (up to 3 by 4 cm in size) also occur within the cleavelandite-rich replacement zone.

The blocky potassium feldspar-quartz-petalite core constitutes the largest zone and varies between 2.1 and 9 m in width and is traceable along strike for 45 m. Secondary, white spodumene + quartz lamellar intergrowths occur as pseudomorphs after primary petalite. The tabular to wedge shapes of the original petalite crystals are distinguishable and vary from 11 cm to 1.3 m in length. A modal analysis over a large exposure near the south end of the pegmatite indicated the presence of 71 volume % petalite, 24 volume % quartz, 4.5 volume % blocky potassium feldspar and trace amounts of muscovite, columbite, and beryl (Breaks 1980).

MINERAL CHEMISTRY

Mineral samples from the MNW pegmatite were examined by Breaks, Selway and Tindle (2003). Electron microprobe compositions of tourmaline, columbite-tantalite, fluorapatite, muscovite and lepidolite are published in MRD 127 (Tindle, Selway and Breaks 2003). Graphs of columbite-tantalite and tourmaline mineral compositions are shown in Figure 14.4. Additional mineral samples collected from this locality during this study will be analyzed in the future.

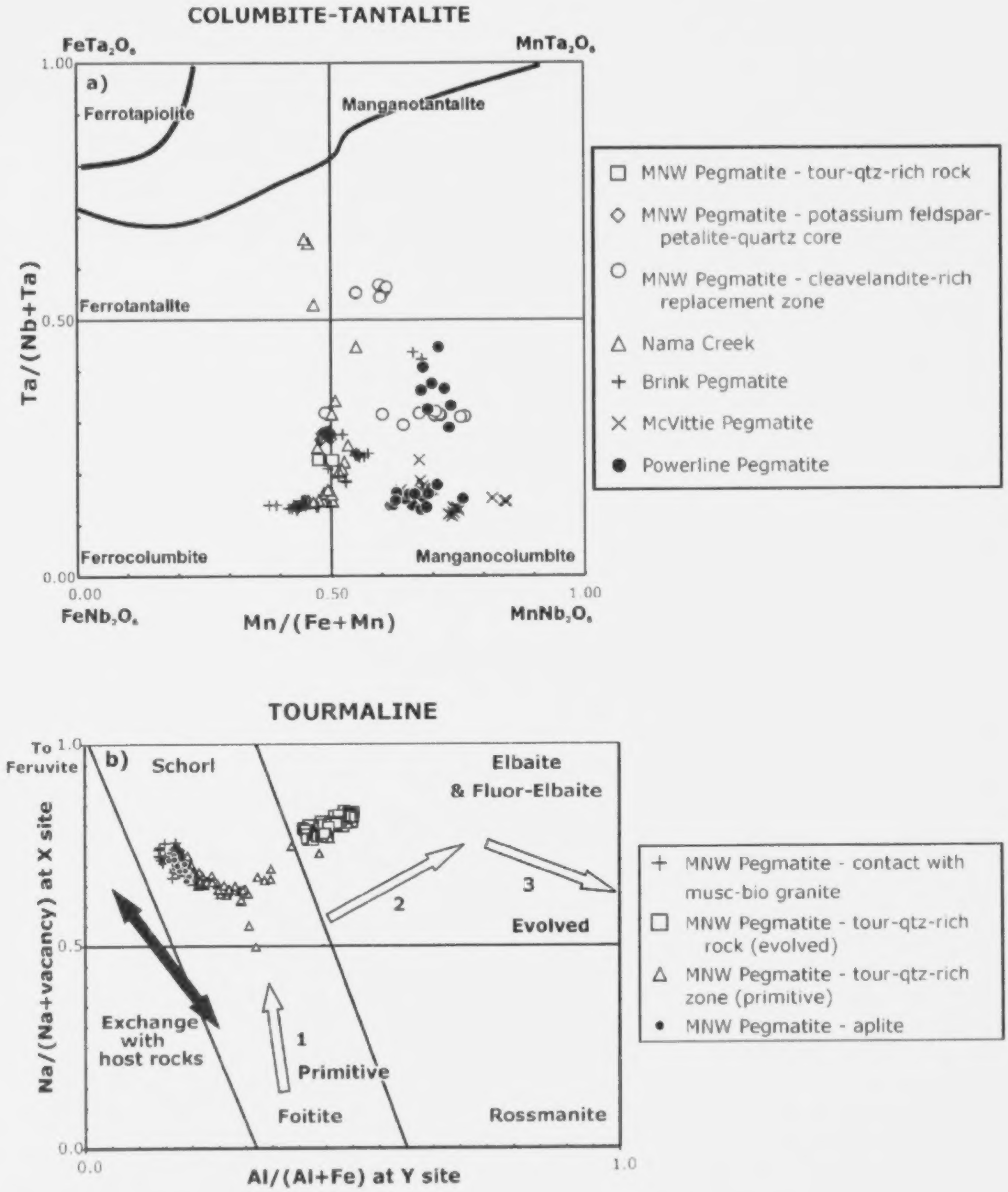

Figure 14.4. a) Ta/(Ta+Nb) versus Mn/(Mn+Fe) for columbite-tantalite minerals from MNW, Brink, McVittie and Powerline pegmatites. b) Na/(Na+vacancy) at X-site versus Al/(Al+Fe) at Y-site for tourmaline from MNW pegmatite.

Tourmaline (magnesium-rich schorl) occurs in the border zone along the contact between the pegmatite and granite. The wall zone contains tantalum-oxide minerals that are intermediate in composition between ferrocolumbite and manganocolumbite (26 weight % Ta_2O_5). The wall zone also contains iron-rich tourmaline and manganese-rich fluorapatite (2.8–4.5 weight % MnO). The green tourmaline ranges in composition from magnesium-bearing schorl to iron-rich elbaite.

The tourmaline-quartz-rich intermediate zone has patches of sugary aplite with tourmaline (iron-rich fluor-elbaite and magnesium-bearing schorl). The fluorapatite is manganese-rich (1.5–3.5 weight % MnO). Both muscovite (0.1–0.4 weight % Rb_2O, <0.1 weight % Cs_2O, 0.6–1.2 weight % F) and rubidium-cesium-fluorine-rich lepidolite (1.1–1.3 weight % Rb_2O, 1.0–1.3 weight % Cs_2O, 4.5–5.6 weight % F) occur in the tourmaline-quartz intermediate zone.

The coarse-grained tantalum-oxide minerals in the cleavelandite-rich replacement zone are mostly manganocolumbite (35–36 weight % Ta_2O_5) and manganotantalite (55–56 weight % Ta_2O_5) with one composition of ferrocolumbite (36 weight % Ta_2O_5). The tantalum-oxide minerals in the petalite core zone are intermediate in composition between ferrocolumbite and manganocolumbite (31–32 weight % Ta_2O_5).

Gathering Lake Pegmatite Group

This pegmatite group was discovered during the present survey and covers a minimum area that is 2 by 7 km in size near the north end of Gathering Lake (*see* Figure 14.2). Two lithium occurrences near Gathering Lake are indicated by Carter, McIlwaine and Wisbey (1972), however, these could not be located. Two beryl occurrences (*see* Figure 14.2) were found during the current survey near the pegmatite group and could represent parental pegmatitic granite for this pegmatite group (i.e., in pegmatitic leucogranite and potassic pegmatite, respectively, at localities 03-FWB-71 (UTM: Zone 16, 459139E, 5474345N) and 03-FWB-80 (UTM: Zone 16, 467617E, 5479831N).

The Gathering Lake pegmatite group comprises 6 tantalum-oxide-bearing albite-type pegmatites that are hosted in medium-grade metasedimentary rocks and biotite granite (localities 03-JBS-74, 03-JBS-79, 03-JBS-77, 03-JBS-70, 03-FWB-68 and 03-FWB-72). Locality 03-JBS-82 (UTM: Zone 16, 462319E, 5478770N) is also an albite-type pegmatite, but tantalum-oxide minerals were not observed. The dikes are identified as "pegmatites" due to the presence of cleavelandite and the abundance of tantalum-oxide minerals. The tantalum-oxide minerals will be analyzed in the future by electron microprobe to determine their tantalum content. The dikes within this group are characterized by the abundance of white cleavelandite (platy habit of albite) and absence of potassium feldspar. All of the pegmatite dikes have an east-striking orientation within a southwest- to northeast-trending zone. The direction of pegmatite evolution is likely southwest to northeast with the northeastern part still open for further rare-element pegmatite discoveries. These dikes differ from the other pegmatite dikes in the study area by the lack of lithium-bearing minerals (i.e., spodumene).

The largest and most evolved albite-type pegmatite in the Gathering Lake pegmatite group occurs at locality 03-JBS-74 (UTM: Zone 16, 466946E, 5482552N). The albite-type pegmatite dike is 29.3 m long with a strike of 250° and intrudes metapelite host rock containing andalusite porphyroblasts. The metapelite host rock has been metasomatized to form a thin aureole of muscovite and tourmaline. The pegmatite dike crosscuts earlier quartz veins. The pegmatite is zoned:

- border zone (5 cm wide) – muscovite + quartz
- muscovite garnet aplite zone with minor green apatite. This zone is locally layered due to lack and/or abundance of garnet and muscovite.

- cleavelandite zone – this is the largest zone and it consists of muscovite-quartz-cleavelandite with minor brown microlite, black garnet and black tantalum-oxide minerals
- quartz pods

A 12 cm wide aplite dike also intrudes the metasedimentary host rock in the same outcrop as the pegmatite dike described above. This dike consists of a tourmaline aplite outer zone and a tourmaline-poor aplite core zone. A similar 7.5 cm wide vein intrudes metasedimentary host rocks at locality 03-JBS-81 (UTM: Zone 16, 462390E, 5479925N). The vein consists of a tourmaline aplite outer zone and a quartz core.

Locality 03-JBS-79 (UTM: Zone 16, 463174E, 5480128N) consists of 3 parallel, and likely genetically related, albite-type pegmatite pods which intrude metasedimentary rocks. The first pod (3.3 m long by 0.6 m wide) consists of a tourmaline aplite outer zone and cleavelandite core zone. The cleavelandite core zone consists of cleavelandite and aplite and minor tourmaline, green beryl and garnet. The other 2 pods are similar in mineral composition with a 0.5 cm wide quartz border zone, tourmaline aplite zone (minor garnet and rare apatite) and cleavelandite + quartz core zone (minor tantalum-oxide minerals, tourmaline and garnet are also present).

Localities 03-JBS-76 (UTM: Zone 16, 468488E, 5484718N), 03-JBS-77 (UTM: Zone 16, 468486E, 5484734N) and 03-JBS-78 (UTM: Zone 16, 468482E, 5484763N) consist of 3 parallel albite-type pegmatite dikes that are in close proximity to each other and are likely genetically related. The dikes intrude white, fine-grained biotite granite. The largest dike (locality 03-JBS-77) is 1.5 m minimum width by 10.7 m minimum length. The dike is homogeneous and consists of quartz, aplite, albitized potassium feldspar, tantalum-oxide minerals and minor muscovite, biotite and an unknown green mineral. The other 2 dikes are similar in mineralogy.

Locality 03-JBS-70 (UTM: Zone 16, 464554E, 5479346N) consists of 3 parallel albite-type pegmatite dikes intruding white fine-grained biotite granite. The largest dike (70 cm wide) consists of 2 pegmatite zones: a) potassium feldspar outer zone consisting of potassium feldspar, albite, quartz and minor tantalum-oxide minerals; and b) an aplite core zone with abundant tantalum-oxide minerals and minor garnet.

Locality 03-JBS-82 (UTM: Zone 16, 462319E, 5478770N) consists of an east-striking, albite-type dike that is 25.4 m long by 2.47 m minimum in width. The dike consists mostly of a muscovite-quartz-cleavelandite zone with a quartz + muscovite layer. The muscovite-quartz-cleavelandite zone also contains minor blue apatite and garnet.

TANTALUM-NIOBIUM MINERALIZATION

Electron microprobe analyses collected to date consist of 188 columbite-tantalite and 28 cassiterite analyses (*see* Figure 14.4a). These data include albite-spodumene-type pegmatites from the Postagoni River group (Nama Creek, McVittie, Brink and Powerline pegmatites) and the complex-type petalite-subtype MNW pegmatite from the Cosgrave Lake group. Most analyses fall into the manganocolumbite field. Oxide minerals with higher tantalum contents were only found at the MNW pegmatite (manganotantalite) and the Nama Creek pegmatite (ferrotantalite). The Nama Creek pegmatite contains the greatest range in Ta/(Nb +Ta) ratios (0.14 to 0.65) whereas the MNW pegmatite exhibits the largest range in Mn/(Mn +Fe) ratios (0.48 to 0.77). The Nama Creek pegmatite shows an iron-rich trend from intermediate ferrocolumbite-manganocolumbite compositions to ferrotantalite compositions. Thus, the Nama Creek pegmatite oxide compositions fractionated by increasing tantalum content. The MNW pegmatite oxide compositions appear to fractionate by increasing manganese content, but more data are required to better define this trend.

Nine new oxide mineral occurrences, likely to be tantalum-niobium bearing, were found during the present survey, 6 of which are from the Gathering Lake pegmatite group. These include the following localities and will be the subject of future electron microprobe analysis:

- 03-FWB-38 (UTM: Zone 16, 434529E, 5453627N): Cosgrave Lake pegmatite group; coarse black grain in apatite-biotite-tourmaline-muscovite potassic pegmatite dike, 1 m thick, hosted in metawacke
- 03-FWB-52 (UTM: Zone 16, 451153E, 5459747N): on John Ahl Road near Barbaro Lake; a single 5 mm diameter grain in biotite-muscovite pegmatitic leucogranite
- 03-FWB-72 (UTM: Zone 16, 468191E, 5483596N): Gathering Lake pegmatite group; tiny black specks in aplite
- 03-FWB-68 (UTM: Zone 16, 467125E, 5483282N): Gathering Lake pegmatite group; numerous fine grained black grains in 1 m thick apatite-garnet-muscovite aplite dike
- 03-JBS-74 (UTM: Zone 16, 466946E, 5482552N): Gathering Lake pegmatite group; numerous fine-grained black grains occur in the cleavelandite zone of this albite-type pegmatite dike
- 03-JBS-79 (UTM: Zone 16, 463174E, 5480128N): Gathering Lake pegmatite group; fine-grained black grains occur in the cleavelandite + quartz core zone of 2 albite-type pegmatite pods at this location
- 03-JBS-77 (UTM: Zone 16, 468486E, 5484734N): Gathering Lake pegmatite group; numerous fine-grained black grains occur in the aplite within 3 albite-type pegmatite dikes at this location
- 03-JBS-70 (UTM: Zone 16, 464554E, 5479346N): Gathering Lake pegmatite group; abundant black grains occur in the aplite core zone, whereas the oxide grains are less abundant in the potassium feldspar outer zone of this albite-type pegmatite dike
- 03-JBS-94: (UTM: Zone 16, 436668E, 5471902N): Lake Jean pegmatite group; platy oxides in aplite border unit of muscovite potassic pegmatite dike

RECOMMENDATIONS FOR EXPLORATION

All of the albite-spodumene-type pegmatite dikes and the MNW petalite-subtype pegmatite in the Georgia Lake area have potential to contain tantalum and lithium mineralization (Pye 1965). Of the previously studied pegmatites in this area, the MNW pegmatite is the most evolved as it contains manganotantalite.

A general rule for the rare-element pegmatites in Ontario is that tantalum mineralization is associated with lithium mineralization in the form of spodumene and/or petalite. The 6 albite-type pegmatites of the Gathering Lake pegmatite group are an exception to this rule, as they all contain niobium-tantalum-oxide minerals, but no lithium minerals. The oxide minerals and bulk aplite samples from these dikes will be analyzed to determine their tantalum contents. Albite-type pegmatites are known to be hosts for significant tantalum mineralization. For example, ore from the past-producing albite-type Wodgina main-lode pegmatite orebody in Western Australia supplied up to 80% of the world's tantalum requirements prior to World War II (Sweetapple, Cornelius and Collins 2001). The Wodgina mine currently extracts tantalum from the albite-spodumene-type Mount Cassiterite pegmatite group and Mount Tinstone pegmatite open pits. The Wodgina Mine is the world's second largest hard rock tantalum resource with an estimated mine life of in excess of 40 years (www.sog.com.au) [accessed October 9, 2003].

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15. Project Unit 95-014. Regional Geology of the Lac des Iles Area

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INTRODUCTION

The Lac des Iles area represents an economically important locality for mining and mineral exploration in Ontario. Situated approximately 100 km north-northwest of Thunder Bay, Ontario, the Lac des Iles area encompasses several mafic to ultramafic intrusions with associated mineralization of palladium, platinum, gold, copper and nickel. North American Palladium Ltd.'s Lac des Iles Mine currently produces platinum group and base metals from the Lac des Iles complex. This and other intrusions have been the focus of extensive mineral exploration in recent years.

Considerable geologic work has been done previously in the Lac des Iles area. For example, the geology of the Lac des Iles area has been studied at a regional scale by Kaye (1966, 1969), Pye (1968), Sage et al. (1974) and Sutcliffe and Smith (1988). The 3 largest intrusions were mapped in detail by Smith and Sutcliffe (1987) and Sutcliffe and Sweeny (1986). Aspects of the geology and mineralization in mafic intrusions of the Lac des Iles area were studied by Watkinson and Dunning (1979), Sutcliffe, Sweeny and Edgar (1989), Talkington and Watkinson (1984), Brugmann and Naldrett (1987), Lavigne and Michaud (2001) and Vaillancourt et al. (2003). Generally, the regional mapping was done at an early stage whereas later research has been focussed on the geology and mineralization of individual mafic intrusions.

The need to update older geologic maps, combined with other factors justified a new examination of the regional geology of the Lac des Iles area. Among these factors is the development of an extensive new network of logging roads that greatly improved access and bedrock exposure in many parts of the area. Further, the Garden–Obonga airborne geophysical survey (Ontario Geological Survey 2002) provides modern high-resolution aeromagnetic data useful for the interpretation of regional geology. Numerous detailed geologic investigations have been made recently by mineral exploration companies (Assessment Files, Resident Geologist's Office, Thunder Bay). These detailed studies greatly increase the level of geologic information in the area, but also create the need for a coherent regional geologic map as a framework for comparison. As a result, a regional geologic survey of the Lac des Iles area was undertaken in 2003. A description of the results of the mapping and interpretations are discussed below.

TECTONIC SETTING

The study area represents part of the eastern Central Wabigoon Subprovince and the north margin of the Quetico Subprovince. Recent tectonic interpretations (Tomlinson et al., in press) have subdivided the

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Wabigoon Subprovince into crustal blocks including the Winnipeg River terrane, Marmion terrane and Western Wabigoon terrane. These crustal blocks are thought to have developed independently through the late Mesoarchean and Neoarchean and were tectonically amalgamated at approximately 2.71 Ga.

Regionally, the Winnipeg River terrane includes the Winnipeg River Subprovince and north-central parts of the Wabigoon Subprovince, as well as the north part of the Lac des Iles area (Figure 15.1). It is an old crustal block composed of biotite tonalite and tonalite gneiss with supracrustal enclaves as old as 3.17 Ga (Beakhouse 1991). The old crustal material has been intruded and assimilated by voluminous Neoarchean felsic magmas represented by batholiths of tonalite and granite as well as mafic magmas that erupted in greenstone belts. For example, although volcanic rocks of the Garden Lake greenstone belt erupted at 2726 Ma, they show old neodymium model ages (Tomlinson et al., in press) indicating that they moved through and were contaminated with material representative of the Winnipeg River terrane.

The Marmion terrane includes tonalite of the Marmion batholith (3.0 Ga) and greenstone sequences (range of 3.0 to 2.8 Ga), such as occur within the Finlayson Lake and Lumby Lake greenstone belts. The sequences younger than 3.0 Ga show neodymium isotopic evidence of having assimilated material of the Marmion batholith (3.0 Ga) and, therefore, represent volcanism that took place in a subaqueous sialic environment (Tomlinson et al., in press). Volcanic rocks of the Heaven Lake greenstone belt (*see* Figure 15.1) have an age of 2953 Ma (Tomlinson et al. 2003) and comprise the only known Mesoarchean rocks representative of the Marmion terrane within the present area. Recent mapping (Stone 2002) shows that the contiguous Marmion batholith occurs west of the present area and available geochronology (discussed below) has not identified Mesoarchean plutonic rocks in the Lac des Iles area. Nonetheless, Tomlinson et al. (in press) have interpreted, on the basis of neodymium isotopic data, that the Marmion terrane extends eastward through the Lac des Iles area. Consequently, plutons of the present area possibly represent material at least partly recycled from the Marmion batholith and associated 3 billion year old plutonic rocks.

The Western Wabigoon terrane occurs more than 100 km west of the present area and includes greenstone belts interspersed with plutonic domains from Savant Lake through Sioux Lookout to Kenora and Fort Francis. During the Neoarchean, the Western Wabigoon terrane developed in an oceanic environment without interacting with older crustal material and was tectonically joined to the Marmion and Winnipeg River terranes. The northern part of the Quetico Subprovince in the Lac des Iles area (*see* Figure 15.1) is composed of well-bedded wacke–siltstone sequences with minor conglomerate units. The wacke–siltstone sequences and conglomerate are correlated with the Quetico Subprovince and Seine group, respectively. Deposition of Quetico sediments in the Atikokan area is bracketed at 2698 to 2688 Ma (Davis, Pezzutto and Ojakangas 1990). A tonalite cobble in conglomerate near Legris Lake has an age of 2684±10 Ma (Percival and Sullivan 1986) and provides a maximum depositional age for the conglomerate. The wacke-siltstone sequences are interpreted as the vestiges of a sedimentary prism that developed during accretion of the amalgamated Wabigoon Subprovince (Winnipeg River, Marmion and Western Wabigoon terranes) and the Wawa Subprovince (Percival and Williams 1989) with conglomerate deposited in late pull-apart basins.

REGIONAL GEOLOGY

The Lac des Iles area is accessible by a network of forest access roads, principal of which are the Dog River road that extends north from Highway 17 at Raith and Highway 811 and the Lac des Iles Mine road that extend easterly from Highway 527 (*see* Figure 15.1). Parts of the Lac des Iles area were previously mapped by Kaye (1964, 1966, 1969), Pye (1968), Sage et al. (1974) and Sutcliffe and Smith (1988). In recent years, northern and eastern parts of the area were studied by Hart et al. (2000a, 2000b) and Hart, Macdonald and Lepine (2001a, 2001b) and geologic information presented here is partly derived from their work. Further, construction of detailed maps of mafic intrusions in the Lac des Iles area benefited greatly from detailed geologic maps generously provided by Houston Lake Mining Inc., North American Palladium Ltd. and Platinum Group Metals Ltd.

Supracrustal Rocks

The Lac des Iles area is underlain by parts of 3 east-trending Archean greenstone belts interspersed with felsic plutonic domains. From north to south, the greenstone belts are the Garden Lake, Heaven Lake and Lac des Iles belts (*see* Figure 15.1).

Hart (2000) described the Garden Lake greenstone belt as a dominantly east-striking, south-facing sequence of mafic volcanic flows with minor units of intermediate to felsic volcanic rocks and iron formation. A thin unit of felsic tuff in the south part of the belt is dated at 2725.5±1.3 Ma (Tomlinson et al. 2003).

The western Heaven Lake greenstone belt in the Mirage Lake–Bo Lake area is separated from the eastern Heaven Lake greenstone belt in the Heaven Lake–Saubrei Lake area (*see* Figure 15.1) by a poorly exposed and presently unmapped area. Previous surveys (e.g., Sage et al. 1974) have interpreted continuity between the western and eastern parts of the belt. The western Heaven Lake greenstone belt is composed of a foliated to gneissic and generally south-dipping sequence of mafic volcanic rocks (up to 7 km wide). Thin units of gabbro and iron formation, the latter of which contain pyrite, pyrrhotite and minor chalcopyrite mineralization (Stone 2002) occur in the mafic sequences.

The eastern Heaven Lake greenstone belt is divided into the Whitton and Whistle assemblages (Hart and Macdonald 2000). The Whitton assemblage occurs extensively in the north and is composed of mafic volcanic flows with lesser units of intermediate to felsic tuffs. The Whitton assemblage probably extends west through the Mirage Lake–Bo Lake area. East of the present area, felsic tuff and a felsic dike in the Whitton assemblage have ages of 2953.7±1.1 Ma and 2953.1±1.6 Ma, respectively (Tomlinson et al. 2003). The Whistle assemblage, occurring south of the Whitton assemblage and east of the present area, is made up of intermediate to felsic fragmental rocks. A U/Pb zircon age of 2729±2 Ma for a sample of felsic tuff from the Whistle assemblage indicates a wide time gap between the eruption of the Whitton and Whistle assemblages.

In the present area, a narrow central panel of the Lac des Iles greenstone belt extends from south of Legris Lake to south of Wakinoo Lake (*see* Figure 15.1). Greenstone sequences 2 km north of Legris Lake and east of the present area comprise part of a south-facing northern panel of the Lac des Iles greenstone belt (Hart, Macdonald and Lepine 2001a). A dacite tuff from the northern panel has an age of 2727.8±1.3 Ma (Tomlinson et al. 2003). Kaye (1969) recognized a third panel of mafic volcanic rocks within sedimentary sequences south of the present area and grouped these with the Lac des Iles greenstone belt.

The thin central panel of the Lac des Iles greenstone belt is dominated by well-foliated to gneissic mafic volcanic rocks although south-facing pillows are recognized south of Wakinoo Lake. Narrow units of green, intermediate to felsic, commonly fragmental volcanic rocks as well as chert units are mingled with the mafic sequences. Also present within the greenstone belt, as well as in sedimentary rocks to the south, are elongate units of grey, feldspar-phyric and typically fragmental felsic volcanic rocks. The grey siliceous volcanic units are possibly alkalic as indicated by the feldspar phenocrysts.

Well-bedded, generally north-facing wacke-siltstone sequences of the Quetico Subprovince occur in the southeast corner of the Lac des Iles area (*see* Figure 15.1). The sedimentary sequence shows southward-increasing metamorphic grade with mineral assemblages dominated by chlorite giving way southward with the development of biotite-, hornblende- and garnet-bearing mineral assemblages. Conglomerate occurs locally at Legris Lake and discontinuously along the south side of the central panel of the Lac des Iles greenstone belt. Iron formation is interbedded with clastic sedimentary rocks at the north margin of the Quetico Subprovince and causes a strong linear magnetic anomaly in this area (Ontario Geological Survey 2002).

Felsic to Intermediate Plutonic Rocks

Felsic plutonic rocks of the central Wabigoon Subprovince have been previously subdivided on the basis of mineralogy, texture and composition into suites including the gneissic suite, biotite tonalite suite, hornblende tonalite suite, biotite granite suite, peraluminous suite and sanukitoid suite (Stone 2002). All suites except the peraluminous suite occur in the Lac des Iles area.

Gneissic rocks occur as irregular units at scattered localities such as north of Muskeg Lake, north of Wakinoo Lake and in the Bonnie Lake area (*see* Figure 15.1). Gneisses are heterogeneous layered rocks with compositions varying from tonalite to granodiorite and include layers of amphibolite, diorite and gabbro. Crosscutting relationships suggest that gneisses are among the oldest plutonic rocks. A sample of tonalite gneiss from an unknown locality in the Lac des Iles area yielded an assortment of zircon grains ranging in age from 2775 to 2722 Ma (Davis 2003). These may represent a mix of crystallization ages for various components of the gneiss as well as young metamorphic zircon grains.

Biotite tonalite occurs widely in the Lac des Iles area, such as at Buck Lake, Armistice Lake and Grew Lake. Biotite tonalite is typically coarse grained and variously massive to foliated and weakly gneissic and grades to granodiorite. Biotite tonalite appears to comprise early batholithic complexes. The ages of these complexes are unknown, but are probably younger than the Marmion batholith (3.0 Ga) because recent mapping shows that the tonalite complexes of the present area are not connected to the Marmion batholith (Stone 2002).

Hornblende tonalite is distributed widely, such as at Mooseland Lake, Weaver Lake and in a batholith southwest of Lac des Iles. Hornblende tonalite is coarse grained and foliated and has from 10 to 20% hornblende and biotite. The development of potassium feldspar megacrysts causes local compositional gradations to granodiorite and granite. The intrusion southwest of Lac des Iles has an age of 2727.8±1.5 Ma (Davis 2003) and, therefore, is very similar in age to volcanic sequences of the Garden Lake belt, the Whistle assemblage of the Heaven Lake belt and the Lac des Iles belt.

Biotite granite occurs in forms ranging from large batholiths, such as at Muskeg Lake and north of Buck Lake, to plutons and dikes intruding most other lithologies. Biotite granite is typically coarse grained, massive to weakly foliated and is potassium feldspar megacrystic in the Muskeg Lake batholith. The ages of biotite granite units in the present area are probably represented by the White Otter batholith and Indian Lake batholith 150 km west, which are 2685 Ma (Davis 1993) and 2671 Ma (Tomlinson et al., in press), respectively.

Rocks of the sanukitoid suite range compositionally from gabbro through diorite and monzodiorite to monzonite. These quartz-undersaturated phases typically contain up to 40% clinopyroxene, hornblende and biotite and may contain inclusions of hornblendite. Quartz-saturated phases of hornblende granodiorite and hornblende granite have possibly evolved by fractionation of the more primitive phases and comprise large parts of some sanukitoid batholiths. Rocks of the sanukitoid suite are coarse grained and massive to weakly foliated. The pluton at Pakashkan Lake and the crescentic intrusion east of Muskeg Lake are composed mainly of hornblende granodiorite. The Shelby Lake batholith is a newly defined pluton of the sanukitoid suite that extends from Wakinoo Lake to Legris Lake (*see* Figure 15.1). The Shelby Lake batholith hosts several platinum group element (PGE) occurrences and is discussed further below. Plutons of the sanukitoid suite were emplaced late in the tectonic evolution of the central Wabigoon Subprovince. Ages of sanukitoid plutons include 2696 Ma for the Roaring River complex (north of the present area) and 2688±4 Ma for the Blalock pluton at Sapawe (Tomlinson et al. in press; Davis, Pezzutto and Ojakangas 1990).

Mafic to Ultramafic Plutonic Rocks

Archean mafic to ultramafic intrusions are represented by the Lac des Iles suite, which includes intrusions at Buck Lake, Dog River, Taman Lake, Tib Lake and the Northern Ultramafic intrusion and Mine Block intrusion at Lac des Iles (*see* Figure 15.1). These intrusions range in size from 1 to 10 km and vary compositionally from leucogabbro and gabbronorite with rare anorthosite to peridotite and pyroxenite. Hornblende gabbro and hornblendite occur widely in most intrusions. The Lac des Iles suite is economically important and hosts North American Palladium Ltd.'s Lac des Iles Mine and numerous occurrences of platinum group elements and base metals.

The Lac des Iles suite probably represents a continuum of the Quetico suite of mafic to ultramafic intrusions (MacTavish 1999; Pettigrew, Hattori and Percival 2000) that are scattered 200 km west-southwest from Lac des Iles through the southern Wabigoon and northern Quetico subprovinces. The late mafic to ultramafic intrusions crosscut most other rock types with the exception of discordant leucocratic biotite granite dikes. Gabbro pegmatite from the Tib Lake intrusion and the Mine Block intrusion have ages of 2685.9±1.6 Ma and 2689.0±1.0 Ma, respectively (Davis 2003). The geology of each intrusion of the Lac des Iles suite is discussed further below.

Archean rocks of the Lac des Iles area are cut by Proterozoic diabase dikes and sills of the Nipigon Sill complex. The diabase is typically coarse grained, massive, black weathering brown and locally contains pyroxene phenocrysts. The diabase sills become increasingly extensive eastward through the area (*see* Figure 15.1) and largely blanket Archean rocks 30 km east of Lac des Iles. Two samples of diabase sills from the Lake Nipigon area have ages of 1108.8+4/–2 Ma (Davis and Sutcliffe 1985). Where diabase sills are intruded into Archean rocks such as in the Lac des Iles area, they are characterized by magnetic lows relative to Archean rocks (Ontario Geological Survey 2002).

Faults

Two regional faults are mapped in the Lac des Iles area. The Gull Lakes fault can be traced southwest from the northeast corner of the area through Chisamore Lake to Jack Lake and Tib Lake where it bifurcates and extends through the Buck Lake area (*see* Figure 15.1). Along most of its length, the Gull Lakes fault is distinguished by red mylonitized tonalite within a linear low airborne magnetic anomaly (Ontario Geological Survey 2002). A splay of the Gull Lakes fault offsets the Tib Lake intrusion, cuts through the northern part of the Dog River intrusion and extends to the Buck Lake intrusion. Poor exposure and lack of high-resolution geophysics precludes definition of the fault southwest of Buck Lake.

The Shelby Lake fault is a 1 km wide zone of mylonite that dips southeast and extends northeast from Wakinoo Lake along the margin of the Shelby Lake batholith. Structural data discussed further below (*see* "Shelby Lake Batholith") indicates thrust displacement on this fault. The Shelby Lake fault clearly cuts diorite of the Shelby Lake batholith at Wakinoo Lake, however, the fault curves and abruptly disappears adjacent to the northern part of the Shelby Lake batholith 2 km south of the Mine Block intrusion (*see* Figure 15.1). These relationships suggest that either the Shelby Lake fault terminates south of the Mine Block intrusion (the displacement diminishes to zero at this point) or else northern parts of the Shelby Lake batholith have been displaced over top of the fault.

Two pieces of evidence favour the latter of the above interpretations. Firstly, the Shelby Lake fault is characterized by a broad zone of mylonite with associated high-shear strain only a few kilometres south of the apparent terminus. The large component of shear strain cannot dissipate over a short distance and hence, the fault must have originally extended much farther north. Secondly, the north end of the Shelby Lake batholith is unusually well foliated and shows a chaotic distribution of shear zones and felsic veinlets that are inconsistent with the strongly localized planar shear strain of the Shelby Lake fault. These observations can be explained by a model in which the Mine Block intrusion has intruded the Shelby Lake batholith causing localized deformation and displacement of a nappe of batholithic material onto the Shelby Lake fault. In this case, the 2689 million-year-old Mine Block intrusion must be younger than the Shelby Lake batholith as well as most of the deformation associated with the Shelby Lake fault. This model is to be tested by determining the age of the Shelby Lake batholith.

GEOLOGY OF THE MAFIC TO ULTRAMAFIC INTRUSIONS

Buck Lake Intrusion

The Buck Lake intrusion, situated at Buck Lake (*see* Figure 15.1) represents the westernmost body of the Lac des Iles suite. The central and eastern parts of the Buck Lake intrusion can be accessed by driving or walking along a network of forest access roads and skidder tracks extending west from the Dog River road as well as by boat on the Dog River north of Buck Lake. Western parts of the intrusion are accessible by forest access roads extending north of the Sideen road.

Composed of hornblende gabbro and lesser hornblendite, pyroxenite and gabbro breccia, the Buck Lake intrusion is an elongate body with a northeast-trending long axis that extends over a distance of 7 km attaining a maximum width of 1.5 km (Figure 15.2). Limited structural data indicates that the intrusion dips steeply to the south. The Buck Lake magma intruded country rocks comprising biotite tonalite and biotite granite. The country rocks within a few kilometres of the intrusion are cut by dikes of gabbro and hornblendite and an irregular mass of mafic to ultramafic rocks (approximately 500 m long) occurs in biotite tonalite 3 km northeast of Buck Lake (*see* Figure 15.2). The Buck Lake intrusion lies along the trace of the East Dog River fault although mafic to ultramafic rocks within the intrusion are not strongly sheared possibly indicating that the intrusion postdates the fault.

Rocks of the Buck Lake intrusion are locally well exposed within trenches recently excavated by mineral exploration companies. Clinopyroxenite, which is partly altered to amphibole, occurs at the north side of the intrusion at the Dog River (*see* Figure 15.2). Clinopyroxenite and hornblendite are intruded by voluminous typically coarse-grained massive hornblende gabbro and hornblende leucogabbro. Gabbro breccia occurs sporadically. The breccia consists of angular blocks of hornblendite, hornblende melagabbro and rare tonalite within a matrix of hornblende gabbro and hornblende leucogabbro. Dikes of hornblendite, hornblende porphyry and white granodiorite represent the latest magmatism at Buck Lake.

The Buck Lake intrusion was explored recently by Buck Lake Ventures Ltd. and North American Palladium Ltd. Exploration by Buck Lake Ventures Ltd., in 2001 included geological mapping, stripping, trenching, prospecting, geochemical surveys and sampling focussed in the area of the copper-nickel-palladium-platinum-gold showing 500 m northeast of Buck Lake (*see* Figure 15.2). Selected grab samples of mineralized pyroxenite contain 5% coarse-grained magnetite, disseminated magnetite and 50 to 60% coarse-grained blebs and disseminated grains of pentlandite, pyrrhotite and chalcopyrite. This material yielded assays of up to 31.6 g/t Pd, 2.82 g/t Pt, 9.96% Ni and 1.53% Cu (Buck Lake Ventures Ltd., Company Press Release, October 2, 2001, Resident Geologist's Files, Thunder Bay). Systematic exploration by North American Palladium Ltd from 1998 to 2001 resulted in the discovery of 10 platinum-palladium occurrences, broadly distributed, with assays ranging from 0.54 to 2.57 g/t (Pt+Pd).

Dog River Intrusion

The Dog River intrusion is situated approximately 7 km east of Buck Lake (*see* Figure 15.1) and can be reached from several logging roads that extend east from the Dog River road. The Dog River intrusion is represented by a cluster of 6 lobate bodies ranging in size from a few hundred metres to 1 km. The intrusions are composed of hornblende gabbro, leuco-hornblende gabbro and hornblendite (Figure 15.3).

Airborne geophysical maps (Ontario Geological Survey 2002) show a roughly circular aeromagnetic anomaly (5 km diameter) centred on the cluster of small gabbroic bodies. Based on gravity modelling, Gupta and Sutcliffe (1990) concluded that the aeromagnetic anomaly represents a mafic intrusion that extends from 500 to 1500 m depth beneath a thin veneer of felsic plutonic country rocks. In this context, the gabbro bodies mapped at surface may represent apophyses of the underlying mafic intrusion that have penetrated the felsic plutonic veneer.

Hornblende gabbro, leuco-hornblende gabbro and hornblendite of the Dog River intrusion are typically coarse grained and massive. The hornblende-bearing rocks have intruded biotite tonalite and lesser components of hornblende tonalite and biotite granite. The East Dog River fault, which extends between the Buck Lake and Tib Lake intrusions passes through the north part of the aeromagnetic anomaly corresponding with the Dog River intrusion.

A zone of breccia (agmatite), comprising rounded clasts of tonalite with mafic selvages in a matrix of fine-grained felsic material, occurs 1.5 km south of the Dog River intrusion (*see* Figure 15.3). Sutcliffe and Sweeny (1986) suggested that the breccia zone could have originated by explosive degassing of the mafic magma chamber of the Dog River intrusion.

Low-grade PGE mineralization has been detected by Platinum Group Metals Ltd. within hornblendite and locally within pegmatitic phases of hornblende gabbro. Values of up to 0.199 g/t (Pd+Pt+Au) have been returned from samples of visibly unmineralized hornblendite within the large central lobe of hornblendite (*see* Figure 15.3).

Taman Lake Intrusion

The Taman Lake intrusion occurs at Taman Lake on the Dog River (*see* Figure 15.1) and is accessible by the Roenicke road, which extends east from the Dog River road. The Taman Lake intrusion is poorly exposed and is possibly composed of 2 separate bodies of mafic to ultramafic rocks. The northern body is represented by several outcrops of coarse, massive hornblendite dispersed east-northeasterly over a distance of 1 km across the Dog River. The northern intrusive body may have an overall dike-like form.

The southern body of the Taman Lake intrusion is exposed in trenches at sides of the Roenicke road and is composed of coarse black hornblendite, hornblende pyroxenite and gabbro. The mafic rocks are cut by white leucocratic granodiorite dikes. Outcrops of biotite tonalite and tonalite gneiss occur sporadically around Taman Lake and constrain the surface exposure of the Taman Lake intrusion to be less than 2 km in width.

Like the Dog River intrusion, the Taman Lake intrusion has an aeromagnetic anomaly that is larger that the surface exposure of mafic to ultramafic rocks (ODM–GSC 1965). Gupta and Sutcliffe (1990) concluded from gravity modelling that the southern body of the Taman Lake intrusion attains a width of approximately 2 km beneath a thin veneer of tonalitic and gneissic country rocks.

The aeromagnetic anomaly associated with the Taman Lake intrusion curves discontinuously eastward over a distance of 10 km from Taman Lake (ODM–GSC 1965). Biotite tonalite and hornblende tonalite occur extensively in this area and are locally cut by dikes and irregular masses of hornblende gabbro, pegmatitic gabbro and fine-grained amphibolite. The mafic dikes are concentrated 7 to 8 km east of Taman Lake (Taman East occurrence) and correspond with a northeasterly elongate airborne magnetic anomaly of moderate intensity. The coincidence of mafic dikes with the magnetic anomaly provides an indication that mafic rocks can occur at depth over a broad area east of Taman Lake.

Surface sampling of non-sulphide-bearing pyroxene hornblendite adjacent to the Roenicke road by New Millennium Metals Corporation (now Platinum Group Metals Ltd.) has returned values of up to 0.322 g/t (Pd+Pt). Recent exploration activity, 1 to 2 km south of the Roenicke road near the southern margin of the Taman aeromagnetic anomaly, has resulted in discovery of mineralized boulders up to 2 m size. The angular boulders of hornblende gabbro are weakly mineralized with chalcopyrite and pyrrhotite and have returned grades ranging from 0.25 to 1.1 g/t (Pd+Pt+Au).

Bullseye Intrusion

The Bullseye intrusion is distinguished by a strong elliptical aeromagnetic anomaly centred approximately 3 km west-southwest of the south end of Tib Lake (Ontario Geological Survey 2002). Reconnaissance mapping has identified several outcrops of coarse-grained, black massive hornblendite within potassium feldspar megacrystic biotite granite coincident with the aeromagnetic anomaly (*see* Figure 15.1). The hornblendite intrusion appears to be dike-like and is elongate up to 1 km northeasterly attaining a width of up to 100 m.

Tib Lake Intrusion

The Tib Lake intrusion is a large oval pluton of the Lac des Iles suite with a maximum diameter of 7 km and a surface area of approximately 25 km^2. The Tib Lake intrusion is situated at Tib Lake near the headwaters of the Dog River (*see* Figure 15.1) and is accessible by the Dog River road and several forest access roads connected to the Dog River road.

The Tib Lake intrusion was mapped in detail by Smith and Sutcliffe (1987) and the geology and petrography of the intrusion are described by Smith and Sutcliffe (1986) and Smith (1991). These authors noted that the intrusion is the site of a strong airborne magnetic anomaly and a strong positive gravity high. Analysis of the local gravity field (Gupta and Sutcliffe 1990) combined with inward-dipping igneous layering led Smith (1991) to conclude that the Tib Lake intrusion is a steeply inward-dipping, basin-like body extending to a depth of 3 km. The Tib Lake intrusion is tilted northward so that deeper levels of the intrusion are exposed in the south and upper levels are exposed in the north.

Smith and Sutcliffe (1986) divided the Tib Lake intrusion into 4 zones: the Border, Lower, Middle and Upper zones. Subsequent mineral exploration has produced new exposures within trenches in the south part of the intrusion. Peredery (2000) studied the new exposures and refined the distribution of the zones, particularly the Border zone, as shown in Figure 15.4.

The Border zone of Peredery (2000) extends around the southern margin of the Tib Lake intrusion and attains a width of up to 800 m. The Border zone is composed primarily of heterogeneous, coarse-grained to pegmatoidal gabbro, which is generally referred to as varitextured gabbro. Lavigne and Michaud (2001) described varitextured gabbro of the Lac des Iles intrusion as having a broad spectrum of compositions ranging from leuco-gabbro to pyroxenite as well as varied textures. Textures include fine-grained gabbro with medium-grained patches and veinlets, medium-grained gabbro with coarse and pegmatitic patches and veinlets, and coarse-grained gabbro with pegmatitic patches and veinlets. Hornblende occurs widely in varitextured gabbro of the Border zone and biotite and quartz are noted in pegmatoidal phases.

The Lower zone attains a width of 1.5 km and extends along a curved strike length of 6 km in the south part of the Tib Lake intrusion (*see* Figure 15.4). The Lower zone is composed of fine- to medium-grained and generally layered gabbronorite as well as minor rock types. Minor lithologies identified by Smith (1991) are typically confined to single outcrops or layers and include hornblende-poikilitic gabbronorite, olivine melagabbronorite, orthopyroxenite and websterite, leucogabbronorite and anorthosite and magnetite-rich gabbronorite.

The Middle zone stratigraphically overlies the Lower zone and is arcuate in form attaining a width of 1.5 km over a strike length of 7.2 km. The Middle zone is composed of foliated to layered hornblende-bearing gabbronorite. Layering of the Middle zone is defined by wispy to discontinuous zones of anorthosite, leucogabbronorite, melanogabbronorite and websterite interspersed with the hornblende-bearing gabbronorite. The uppermost 400 m of the Middle zone is characterized by magnetite-rich gabbronorite cut by pegmatitic gabbro dikes.

The Upper zone is roughly oval with a diameter of 2 km and is composed of hornblende gabbronorite with layers of magnetite-bearing gabbronorite and inclusion-rich gabbronorite near the base. Inclusions are typically less than 1 m in diameter and include pyroxene granulite and layered gabbronorite and amphibolite. In addition, several large xenoliths of mafic metavolcanic rocks occur in the Upper zone (*see* Figure 15.4).

The Tib Lake intrusion was emplaced into biotite tonalite and biotite granite at 2686 Ma (Davis 2003) and cuts thin greenstone slivers associated with the Heaven Lake greenstone belt. The intrusion is transected by the East Dog River fault, which has produced a right-lateral strike separation of 500 m at the south boundary.

Mineralization occurs locally in the Border and Middle zones and consists of platinum group elements associated with weakly disseminated sulphide minerals in varitextured gabbro (*see* mineral occurrences in Figure 15.4). Houston Lake Mining Inc. intersected 22 m grading 1.246 g/t (Pt+Pd+Au), 0.17% Ni, and 0.15% Cu in hole TL-00-16 at the Kuhner showing (Houston Lake Mining Inc., Company Press Release, October 24, 2000, Resident Geologist's Files, Thunder Bay). A grab sample from the Jewelweed occurrence collected by the Resident Geologist assayed 0.83 g/t Pd, 0.28 g/t Pt, 0.14 g/t Au, 0.31% Cu and 0.06% Ni (Resident Geologist's Files, Thunder Bay).

Lac des Iles Complex

The Lac des Iles complex is the largest and economically most important member of the Lac des Iles intrusive suite. The Lac des Iles complex comprises 2 intrusions including the Northern Ultramafic intrusion and the gabbroic Mine Block intrusion (*see* Figure 15.1). The Lac des Iles complex has intruded biotite tonalite and tonalite gneiss and lies at the north end of the Shelby Lake fault.

NORTHERN ULTRAMAFIC INTRUSION

The Northern Ultramafic intrusion is situated at Lac des Iles and is accessible from the lake and a series of logging roads and skidder tracks extending north from the main road to the Lac des Iles Mine. Sutcliffe and Sweeny (1986) noted that the Northern Ultramafic intrusion is composed of 2 coalescing intrusive centres that are defined by the distribution of lithologies and attitudes of layering.

The northern ultramafic centre is nearly circular in plan with a mean diameter of approximately 4 km (Figure 15.5). It is composed of a layered and possibly folded sequence of peridotite and pyroxenite of which the pyroxenite is volumetrically dominant. Igneous layers are exposed in trenches east of Lac des Iles and range in thickness from a few metres to tens of metres and locally may exceed 100 m. Igneous layers typically have a base of serpentinite and wehrlite (olivine cumulates) grading up through olivine-pyroxenite to websterite and clinopyroxenite (Linhardt and Bues 1987). The tops of igneous layers dip northwest at shallow to intermediate angles and indicate that clinopyroxenite at the northwest end of Lac des Iles may represent the stratigraphic top of the sequence. However, local reversals in the dip direction are noted (*see* Figure 15.5) and suggest that the stratigraphy of the intrusion may be complicated by faults or folds at the northwest end of Lac des Iles. Gravity modelling (Gupta and Sutcliffe 1990) indicates that the northern ultramafic centre thickens southward from a depth of 1 km at the north end of Lac des Iles to 3 km at the contact with the southern ultramafic centre.

The southern ultramafic centre is elliptical in plan with a maximum length of 3 km and is centred at Southeast Angle Bay of Lac des Iles. The southern ultramafic centre has an irregular wehrlite core and is surrounded by websterite and locally cut by gabbro. Igneous layering is not well developed so that the structural configuration including stratigraphic top of the intrusive centre is not known. The southern ultramafic centre is interpreted to extend to a depth of 4.5 km and may represent the feeder conduit through which magma was supplied to the Lac des Iles complex (Gupta and Sutcliffe 1990).

Ultramafic rocks of the Northern Ultramafic intrusion show a range of alteration. Olivine tends to be highly altered to serpentine, talc and magnetite although unaltered olivine grains occur in some serpentinites. Pyroxenites tend to be partly altered to amphibole, with clinopyroxene grains showing somewhat stronger alteration than orthopyroxene grains.

Mafic to intermediate rocks are concentrated at margins of the Northern Ultramafic intrusion. Hornblende gabbro and associated hornblendite mantle the west side of both intrusive centres. A spectrum of plagioclase-bearing rocks, including gabbro, gabbronorite, leucogabbro and leucogabbronorite, occur at the east margins of the ultramafic centres and also as thin (>100 m wide) units within the ultramafic sequences. It is unclear whether the thin gabbroic units represent fractionated igneous layers or intrusive sills. Breccias occur locally in the boundary zone between the intrusive centres. The breccias are characterized by a variety of mafic to ultramafic fragments including rare mafic volcanic blocks within a gabbro matrix.

Linhardt and Sutcliffe (1986) systematically sampled the centre of the Northern Ultramafic intrusion and noted several occurrences of disseminated sulphide minerals and chromite, the former of which are associated with websterite. Assays of up to 2.7 g/t (Pd+Pt+Au) were obtained from mineralized websterite. Systematic exploration by North American Palladium Ltd. produced over 300 widely distributed bedrock assays with values greater than 0.5 g/t (Pt+Pd), the highest being 5.4 g/t (Pt+Pd). The results of detailed surface evaluation were negative.

MINE BLOCK INTRUSION

The gabbroic Mine Block intrusion is roughly elliptical in plan with a long axis extending northeasterly over a distance of 4 km. It occurs directly south of the Northern Ultramafic intrusion and Lac des Iles and is traversed by numerous roads in the vicinity of the Lac des Iles Mine (*see* Figure 15.5). The Mine Block intrusion is interpreted as a steeply dipping slab that extends to a depth of 1.5 km (Gupta and Sutcliffe 1990). It is partly separated from the Northern Ultramafic intrusion by a thin septum of tonalite.

The Mine Block intrusion hosts significant palladium, platinum and gold mineralization that was first discovered in 1963 (for a detailed account of exploration of the Mine Block intrusion, *see* Lavigne and Michaud 2001). Mining of the Roby zone was begun by Madeleine Mines Limited (subsequently renamed North American Palladium Ltd.) in 1993 and the mining operation was expanded in the late 1990s. Proven and probable reserves from the Roby zone are 43 990 000 tonnes containing approximately 103 000 kg Pd, 9700 kg Pt, 7300 kg Au, 27 865 000 kg Cu and 34 352 000 kg Ni (North American Palladium Ltd., Company Press Release, August 22, 2003). The Mine Block intrusion was extensively studied in the 1970s and 1980s and various descriptions and interpretations of the geology and mineralization were put forward (e.g. Watkinson and Dunning 1979; Talkington and Watkinson 1984; MacDonald 1985; Sutcliffe, Sweeny and Edgar 1989). With the accumulation of new geologic data derived from exploration boreholes and trenches as well as mining, Lavigne and Michaud (2001) refined the geologic interpretation of the Mine Block intrusion as summarized in Figure 15.5.

The Mine Block intrusion consists of a distinct oval-shaped domain immediately south of Lac des Iles and a second domain farther to the southwest (*see* Figure 15.5). The second domain is in contact with hornblende gabbro of the Shelby Lake batholith at Camp Lake.

The oval domain is concentrically zoned with a rim of varitextured gabbro and a complex core zone composed of gabbronorite breccia, massive medium-grained gabbro, heterolithic gabbro breccia and magnetite gabbronorite. Palladium mineralization, such as at the Roby zone, Baker zone and Creek zone, shows a strong association with varitextured gabbro. The second and southwest domain of the Mine Block intrusion is composed of massive gabbronorite and is barren.

At the Roby zone, Lavigne and Michaud (2001) identified 3 types of ore including breccia, high-grade and North Roby varieties of which the breccia ore is volumetrically dominant. The heterolithic gabbro breccia, which hosts the breccia ore contains fragments representative of most lithologies in the Mine Block intrusion. The fragments are of various sizes and shapes and occur within a gabbro matrix. The gabbro breccia is strongly altered with pyroxene grains converted to actinolite, talc, anthophyllite and serpentine. Plagioclase is altered to zoisite and epidote. Platinum group element (PGE) mineralization is confined mainly to the gabbro matrix (Hinchey, Hattori and Lavigne 2003) and includes kotulskite, merenskyite, braggite and vysotskite associated with fine-grained disseminated pyrrhotite, pyrite, pentlandite and chalcopyrite. The sulphide minerals comprise up to 5% of the breccia matrix.

High-grade ore occurs in a strongly sheared and altered unit of pyroxenite and melanogabbro (up to 25 m wide) in the east central portion of the Roby zone. Pyroxene grains within the host rock are altered to amphibole and chlorite. The altered unit contains up to 3% disseminated sulphide grains. Palladium and platinum mineralization consists predominantly of fine-grained PGE sulphide, braggite and telluride minerals, merenskyite and kotulskite that typically occur as inclusions in secondary silicates (Lavigne and Michaud 2001).

North Roby ore occurs within a tabular zone (200 m long) and is hosted by a variety of lithologies including leucogabbro containing irregular masses of varitextured gabbro, gabbronorite and clinopyroxenite. The leucogabbro is relatively less altered than the host-rock of other ore-types and is locally layered. PGE mineralization consists of braggite and vysotskite associated with a few percent sulphide minerals in gabbronorite and clinopyroxenite.

Lavigne and Michaud (2001) noted a strong association of PGE mineralization with brecciated rock and varitextured gabbro within which magmatic minerals are variously altered to hydrous silicates. These authors concluded that the mineralization resulted from forcible introduction of a PGE- and sulphide-rich magma into the partly crystallized magma chamber of the Mine Block intrusion. The magma crystallized as sills (North Roby ore) and as discordant breccia (breccia ore) exsolving a high-temperature fluid that fluxed through the partially crystallized chamber producing varitextures and subsequently leading to alteration of silicates and local PGE-enrichment (high-grade ore). Vaillancourt et al. (2003) generally concurred with the above interpretation and classified the mineralization of the Mine Block intrusion as having developed through hydrothermal mobilization on the basis of an association of the mineralization with sulphide-poor rocks that have interacted with hydrothermal fluids.

Shelby Lake Batholith

The Shelby Lake batholith is the largest mafic to intermediate intrusion in the Lac des Iles area. Tapered to triangular in shape, it broadens from an apex at Wakinoo Lake over a distance of 33 km to Legris Lake in the east and Camp Lake in the north (*see* Figure 15.1). The Shelby Lake batholith is accessible by a series of logging roads extending from the Dog River road in the west and Highway 527 in the east.

The Shelby Lake batholith is composed of hornblende leucogabbro (diorite) to monzodiorite, hornblende granodiorite to granite and possibly hornblende gabbro (Figure 15.6).

Hornblende leucogabbro occurs widely in the central parts of the Shelby Lake batholith. This rock is massive to weakly foliated, is composed of 20 to 40% amphibole and has somewhat varied proportions of potassium feldspar causing rock compositions to range through monzodiorite and locally to monzonite. Quartz is generally absent, but can locally comprise up to 10% of the leucogabbro.

Hornblende granodiorite, including a coarse-grained potassium feldspar megacrystic granodiorite, occurs within several masses, such as north of Towle Lake and north of Varris Lake (*see* Figure 15.6). The hornblende granodiorite is a late intrusive phase of the batholith and has possibly originated by fractionation of the hornblende leucogabbro.

Hornblende gabbro is coarse grained and typically contains from 40 to 60% amphibole and rare clinopyroxene. Inclusions and small units of pyroxenite and hornblendite are locally associated with hornblende gabbro. The hornblende gabbro is weakly to strongly foliated and occurs at apices of the Shelby Lake intrusion, such as at Wakinoo Lake, Camp Lake and Legris Lake, as well as in thin units at margins of the intrusion, such as east-northeast of Towle Lake (*see* Figure 15.6).

Previous regional mapping surveys (e.g., Sutcliffe and Smith 1988) identified hornblende gabbro units at Wakinoo Lake, Camp Lake and Legris Lake as well as a small mafic to ultramafic body at Demars Lake. Recent mapping by Platinum Group Metals Ltd. has defined the Towle Lake gabbro body that extends as a narrow unit along the margin of the Shelby Lake batholith from Wakinoo Lake to Varris Lake locally attaining a width of 500 m (*see* Figure 15.6). The Towle Lake body ranges compositionally from clinopyroxenite to an iron-rich gabbro with up to 30% magnetite and is responsible for a strong aeromagnetic anomaly in this area (Ontario Geological Survey 2002). Diamond drilling by Platinum

Group Metals Ltd. indicates a sheared contact between hornblende gabbro of the Towle Lake body and hornblende diorite to the north.

Sutcliffe and Smith (1988) grouped the hornblende gabbro bodies with the Lac des Iles suite of mafic to ultramafic intrusions; however, the present work raises the possibility that the hornblende gabbro is an early intrusive phase of the Shelby Lake batholith. As discussed previously (*see* "Felsic to Intermediate Plutonic Rocks"), the Shelby Lake batholith is interpreted as a member of the sanukitoid suite. Intrusions of the sanukitoid suite often have early hornblende gabbro phases containing ultramafic inclusions and can be a few million years older than the Lac des Iles suite. Crosscutting relations indicate that hornblende gabbro at Wakinoo Lake and Camp Lake predates hornblende leucogabbro characteristic of the central mass of the Shelby Lake batholith. These crosscutting relations, combined with geochronologic investigation of the hornblende leucogabbro at Shelby Lake (currently in progress), may constrain the age of the hornblende gabbro bodies and resolve whether or not they are members of the Lac des Iles suite or an early phase of the Shelby Lake batholith.

A small oval body of hornblende gabbro and pyroxenite occurs at Demars Lake and is physically detached from the Shelby Lake batholith (*see* Figure 15.6). Sutcliffe and Smith (1988) interpreted the Demars Lake body to represent an intrusive plug representative of the Lac des Iles suite. However, the new mapping shows that the Demars Lake body occurs within a flat-lying splay of the Shelby Lake fault and is possibly allochthonous material detached from the Shelby Lake batholith. The Shelby Lake fault extends along the northwest margin of the batholith and is marked by a kilometre-wide zone of mylonitized and locally strongly lineated rock. Foliations and stretched mineral lineations are inclined southeast and imply that the Shelby Lake Fault dips in the same direction. Further, the mineral lineations suggest that the fault has accommodated an oblique, primarily dip-slip component of displacement. Two splays of the Shelby Lake fault are recognized in the Wakinoo Lake area. These include a flat-lying to shallow southeasterly dipping splay and a second splay that is inclined to the southeast at a moderate to steep angle. The plane of the nearly flat-lying fault is exposed at surface and is characterized by strongly lineated tonalite that extends within lobes up to 5 km north and northwest of Wakinoo Lake (*see* Figure 15.6 and Figure 15.7). The mafic to ultramafic body at Demars Lake has either intruded into the fault plane or else rests on the nearly flat-lying fault. The latter of these options is illustrated in Figure 15.7 where the Demars lake body is interpreted as a klippe.

Down-dip mineral lineations could have developed on the Shelby Lake fault due to either normal or reverse (thrust) displacement, of which available evidence favours thrust displacement. The geometry of the fault including its low angle of repose and splayed nature are consistent with the geometry of continental thrust faults (e.g., Coward 1994). Further, the ultramafic material of the Demars body can represent deeper levels of the Shelby Lake batholith, which would require that this material be thrust into position from the southeast.

Although the Shelby Lake fault cuts the Shelby Lake batholith at Wakinoo Lake, the fault appears to abruptly terminate against the batholith 2 km south of the Mine Block intrusion. As discussed previously (*see* "Faults"), the fault has possibly been buried at this locality beneath a nappe of batholithic material that was pushed aside by emplacement of the Mine Block intrusion. This model can be substantiated if geochronology shows that the Shelby Lake batholith is older than the Mine Block intrusion.

The Shelby Lake batholith hosts numerous PGE and base metal occurrences. These are associated with varieties of hornblende gabbro in thin units extended along the northwest margin of the batholith and in larger masses, such as at Wakinoo Lake, Legris Lake and Towle Lake.

Mineralization at the margins of the Shelby Lake batholith is represented by the Stocker and Turtle Hill occurrences (*see* Figure 15.6). The Stocker and Turtle Hill occurrences are characterized by low level mineralization (grab samples of up to 1.64 g/t Pt+Pd+Au) associated with disseminated pyrite and chalcopyrite within coarse-grained varitextured hornblende leucogabbro, gabbro breccia and lesser pyroxenite (Wagner 2002). The mineralized hornblende leucogabbro typically occurs within 50 m of the faulted contact of the Shelby Lake batholith and may contain inclusions of hornblende gabbro and pyroxenite. Anomalous PGE mineralization has been discovered by Platinum Group Metals Ltd. over widths of up to 15 m over a distance in excess of 2 km along the contact.

At Wakinoo Lake, a few percent of disseminated chalcopyrite, pyrrhotite and pyrite occur locally within coarse-grained and variously massive to foliated, somewhat varitextured hornblende gabbro. Channel sampling of this material by North American Palladium Ltd produced assays in excess of 0.5 g/t (Pd+Pt), the highest being 4.39 g/t (Pd+Pt) over 1.5 m lengths. Drilling by Buck Lake Ventures Ltd. in 2002 returned 0.46 g/t Pd across 8.56 m (*Canada Stockwatch*, October 9, 2002, Resident Geologist's Files, Thunder Bay). A grab sample collected by the senior author assayed 3.1 g/t Pd, 0.6 g/t Pt, 0.18 g/t Au, 0.57% Cu and 0.17% Ni.

At the Main and Poplar showings near Legris Lake (*see* Figure 15.6), Pettigrew and Hattori (2001) described PGE enrichment within brecciated hornblende leucogabbro that contains sedimentary xenoliths and overlies pyroxenite. Platinum group minerals include Pd-Bi-tellurides, minor Pt-Pd-Bi-tellurides and Pd sulphides within grains of sulphide minerals that typically comprise a few percent of an epidotized gabbroic host rock. Sulphide minerals include pyrite and chalcopyrite and locally pyrrhotite, millerite, pentlandite and magnetite. Diamond drilling in 2000 by Avalon Ventures Ltd. and Starcore Resources Ltd. returned assays of 2.04 g/t Pd, 0.41 g/t Pt, 0.71 g/t Au, 0.42% Cu and 0.13% Ni from a 9.95 m interval of mineralized hornblende gabbro (Avalon Ventures Ltd. and Starcore Resources Ltd., Press Release, November 10, 2000, Resident Geologist's Files, Thunder Bay). Diamond drilling on the Poplar Zone by Avalon Ventures Ltd., Starcore Resources Ltd. and Placer Dome (CLA) Limited intersected 5.12 g/t (Pt+Pd), 0.5% Cu and 0.3% Ni over 0.97 m (Avalon Ventures Ltd., Annual Report, 2001, Resident Geologist's Files, Thunder Bay).

The Towle Lake hornblende gabbro body hosts 3 known zones of PGE mineralization: Powder Hill, Stinger and Vande (*see* Figure 15.6). Platinum group element mineralization at Powder Hill is associated with coarse-grained varitextured leucogabbro, which forms the matrix of a breccia unit 50 m from the southeastern contact of the body. This mineralized zone has been traced by drilling for 600 m along strike and has grades of up to 2.83 g/t (Pt+Pd+Au) over 1.2 m within a broader mineralized zone of 9.5 m width.

At the Stinger zone, high-grade PGE mineralization is developed at the contact between hornblende leucogabbro and an earlier pyroxenite. Mineralization takes the form of finely disseminated chalcopyrite, pyrite and pyrrhotite and yields drill intercepts of up to 6.71 g/t (Pd+Pt+Au) over 1.1 m and 1.06 g/t over 19.2 m. The mineralized zone, which has been traced for over 500 m along strike has subsequently been affected by both ductile deformation and late brittle deformation.

Mineralization at the Vande zone is similar to that of the Powder Hill occurrence and consists of weakly disseminated chalcopyrite and pyrrhotite within varitextured leucogabbro, which contains blocks of melanogabbro, hornblende gabbro and pyroxenite. Locally, in the Vande zone area, there is an overprint of barren pyrite mineralization that weathers as large gossans. This late pyrite mineralization may be related to intrusion of the hornblende leucogabbro of the Shelby Lake batholith. PGE mineralization grading up to 1.95 g/t (Pd+Pt+Au) over 2.0 m has been intersected in diamond drill holes and has been traced for 700 m in the area of the Vande occurrence.

SUMMARY AND RECOMMENDATIONS FOR MINERAL EXPLORATION

At a regional scale, the Lac des Iles area has been interpreted as the highly reworked eastern end of the Mesoarchean Marmion terrane (Tomlinson et al., in press). The 2.95 Ga age of the Whitton assemblage of the Heaven Lake greenstone belt supports this interpretation although the geology and available geochronology for areas south of the Heaven Lake greenstone belt are equivocal. Northeast-trending faults and Neoarchean ages for supracrustal and plutonic sequences provide an indication that material in the southern parts of the Lac des Iles area could have been tectonically joined to older crustal blocks in the north rather than intruded through the older material. Further mapping southwest of the Lac des Iles area adjacent to the contiguous Marmion batholith combined with geochronology focussed on identification of Marmion-age material in the younger plutons will help to resolve the eastern extent of the Marmion terrane.

Mafic to ultramafic intrusions of the Lac des Iles suite show a strong association with faults. All large intrusions occur along the traces of northeast-trending faults. In some instances, the faults cut the intrusion (Tib Lake), whereas in other instances, the faults may have acted as conduits into which the magmas were emplaced (Buck and Mine Block intrusions). Possibly, there are several generations of faults or faulting protracted over a range of time during which the Lac des Iles suite was emplaced. In any case, the association of intrusions with faults provides a useful exploration tool. For example, other mafic intrusions may occur northeast of the present area along the Gull Lakes fault. The geology and geophysics of areas east of Lac des Iles need to be carefully studied for evidence of major faults with associated mafic intrusions beneath the Nipigon Sill complex.

The major intrusions of the Lac des Iles suite have been well defined by previous mapping surveys (e.g., Sutcliffe and Smith 1988). Several small intrusions, such as north of Buck Lake (*see* Figure 15.2), in the Dog River area (*see* Figure 15.3), at Taman Lake, Towle Lake and the Bullseye intrusion (*see* Figure 15.1), have been added to the suite. These have had little mineral exploration and are worthy of further study for platinum group metals.

Smith and Sutcliffe (1987), Smith (1991) and Linhardt and Bues (1987) noted well-developed igneous layering in the Tib Lake and Northern Ultramafic intrusions. As discussed by Vaillancourt et al. (2003), the style of PGE mineralization in layered intrusions is typically stratiform or reef-like and developed at an intermediate to late stage of crystallization and can be associated with thin sulphide mineral or chromite horizons. Mineralized reefs within layered sequences are typically thin and may not be obvious. Exploration for PGEs in layered intrusions, such as are described by Hoatson and Keays (1989), requires a detailed investigation of the geology and crystallization sequence of the intrusion and detailed sampling to identify strata where sulphide saturation and PGE mineralization may have developed. In contrast, the Lac des Iles Mine is classified as a hydrothermal disseminated type of mineralization and is associated with weakly disseminated sulphide minerals in rocks that have had extensive interaction with hydrothermal fluids.

Previous mineral exploration broadly throughout the Lac des Iles area appears to have focussed on a Lac des Iles-type of mineralization and sought out hydrothermally altered rock, whereas a different style of exploration may be more appropriate for the layered sequences. It is recommended that the Tib and Northern Ultramafic intrusions be explored with an eye for reef-type mineralization.

Regional mapping demonstrates that numerous PGE occurrences are associated with hornblende gabbro bodies at margins of the Shelby Lake batholith. The hornblende gabbro bodies may represent vestiges of one or more intrusions of the Lac des Iles suite or may represent an early mafic phase of the Shelby Lake batholith. In either case, the hornblende gabbro bodies warrant further exploration, particularly in the north where the batholithic margins are partly overlain by diabase.

In addition to the Entwine stock (Stone 2000) and the Roaring River complex, the newly defined Shelby Lake batholith provides another example of a sanukitoid intrusion that is either mineralized or else spatially associated with PGE mineralization. Intrusions of the sanukitoid suite occur widely in the western Superior Province. Those with extensive mafic and quartz-undersaturated units are particularly suitable candidates for PGE mineralization.

Finally, the newly defined Gull Lakes and Shelby Lake faults raise the potential for shear zone associated gold mineralization in the Lac des Iles area. For example, gold can be remobilized within faulted zones of the Tib Lake intrusion and possibly south of the Mine Block intrusion. Gold mineralization can also be developed where the Gull Lakes fault cuts the Heaven Lake greenstone belt north of Tib Lake and where the Shelby Lake fault intersects the Lac des Iles greenstone belt southwest of Wakinoo Lake.

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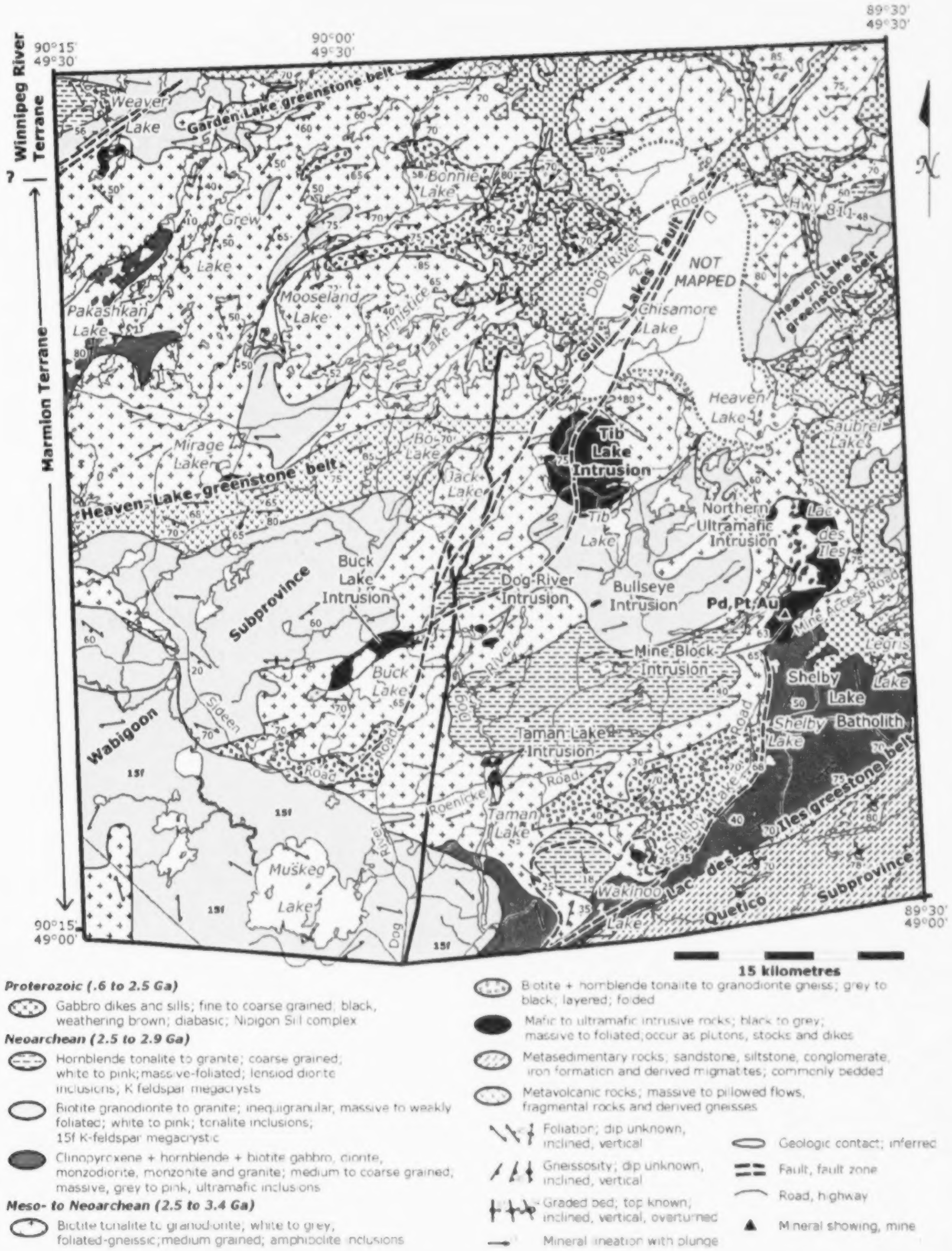
90°15'
49°30'
90°00'
49°30'
89°30'
49°30'
Winnipeg River Terrane
Marmion Terrane
Weaver Lake
Garden Lake greenstone belt
Bonnie Lake
Grew Lake
Pakashkan Lake
Mooseland Lake
Armistice Lake
Dog River
Gull Lakes Fault
Road
Hwy 811
NOT MAPPED
Chisamore Lake
Heaven Lake greenstone belt
Heaven Lake
Saubrei Lake
Mirage Lake
Bo Lake
Jack Lake
Heaven Lake greenstone belt
Tib Lake Intrusion
Tib Lake
Northern Ultramafic Intrusion
Lac des Iles
Buck Lake Intrusion
Wabigoon Subprovince
Dog River Intrusion
Bullseye Intrusion
Pd, Pt, Au
Mine Access Road
Legris Lake
Buck Lake
Mine Block Intrusion
Shelby Lake
Shelby Lake Batholith
Shelby Lake
Sideen Road
Taman Lake Intrusion
Taman Lake
Roenicke Road
Shelby Lake Road
Lac des Iles greenstone belt
Muskeg Lake
Dog River
Wakinoo Lake
Quetico Subprovince
15f
90°15'
49°00'
89°30'
49°00'
N
15 kilometres
Proterozoic (.6 to 2.5 Ga)
Gabbro dikes and sills; fine to coarse grained; black, weathering brown; diabasic; Nipigon Sill complex
Neoarchean (2.5 to 2.9 Ga)
Hornblende tonalite to granite; coarse grained; white to pink; massive-foliated; lensiod diorite inclusions; K feldspar megacrysts
Biotite granodiorite to granite; inequigranular, massive to weakly foliated; white to pink; tonalite inclusions; 15f K-feldspar megacrystic
Clinopyroxene + hornblende + biotite gabbro, diorite, monzodiorite, monzonite and granite; medium to coarse grained; massive, grey to pink, ultramafic inclusions
Meso- to Neoarchean (2.5 to 3.4 Ga)
Biotite tonalite to granodiorite; white to grey, foliated-gneissic; medium grained; amphibolite inclusions
Biotite + hornblende tonalite to granodiorite gneiss; grey to black; layered; folded
Mafic to ultramafic intrusive rocks; black to grey; massive to foliated; occur as plutons, stocks and dikes
Metasedimentary rocks; sandstone, siltstone, conglomerate, iron formation and derived migmatites; commonly bedded
Metavolcanic rocks; massive to pillowed flows, fragmental rocks and derived gneisses
Foliation; dip unknown, inclined, vertical
Gneissosity; dip unknown, inclined, vertical
Graded bed; top known; inclined, vertical, overturned
Mineral lineation with plunge
Geologic contact; inferred
Fault, fault zone
Road, highway
Mineral showing, mine

Figure 15.1. Geology of the Lac des Iles area compiled, in part, *from* Hart et al. (2000a, 2000b) and *from* Hart, Macdonald and Lepine (2001a, 2001b).

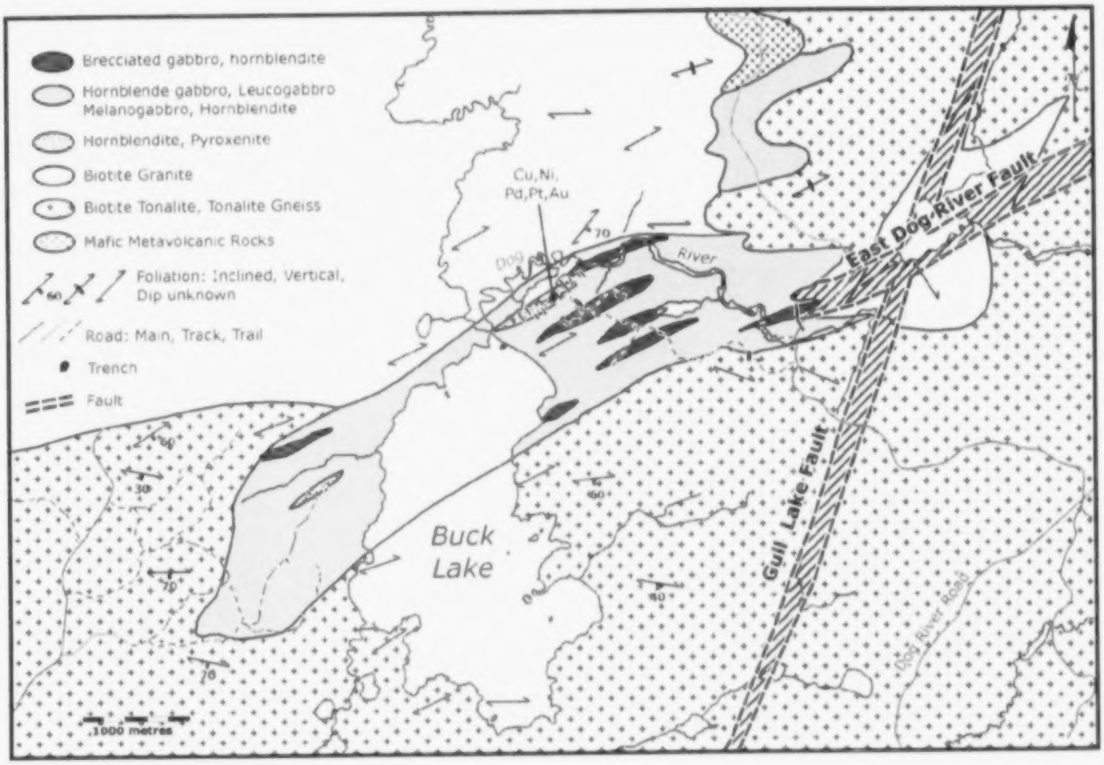
Brecciated gabbro, hornblendite
Hornblende gabbro, Leucogabbro Melanogabbro, Hornblendite
Hornblendite, Pyroxenite
Biotite Granite
Biotite Tonalite, Tonalite Gneiss
Mafic Metavolcanic Rocks
Foliation: Inclined, Vertical, Dip unknown
Road: Main, Track, Trail
Trench
Fault
Cu,Ni,
Pd,Pt,Au
Dog
River
East Dog River Fault
Gull Lake Fault
Buck
Lake
Dog River Road
1000 metres
70
60
30
70
70
60
40

Figure 15.2. Geology of the Buck Lake area compiled, in part, *from* unpublished maps of North American Palladium Ltd.

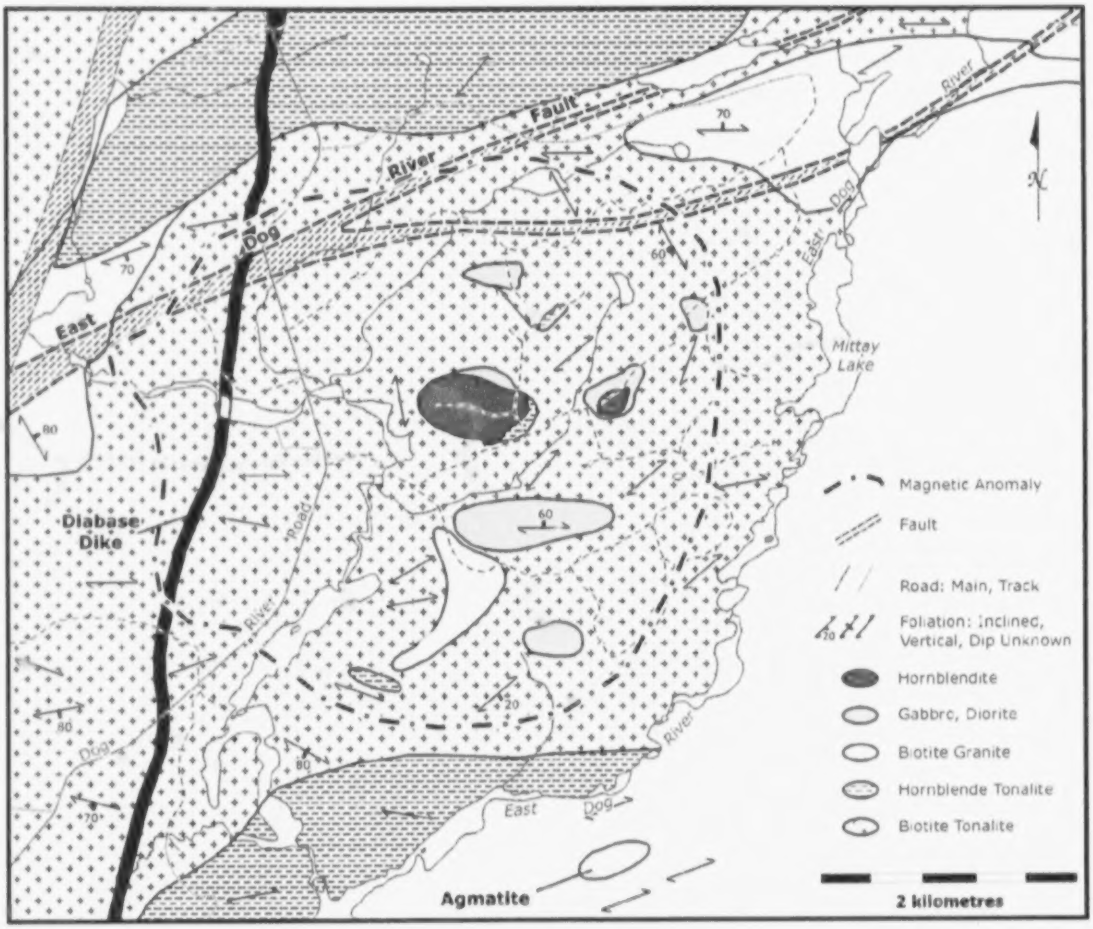
Dog River Fault
East Dog River
Diabase Dike
Road
River
Dog
Mittay Lake
N
70
80
60
20
East Dog
Agmatite
Magnetic Anomaly
Fault
Road: Main, Track
Foliation: Inclined, Vertical, Dip Unknown
Hornblendite
Gabbro, Diorite
Biotite Granite
Hornblende Tonalite
Biotite Tonalite
2 kilometres

Figure 15.3. Geology of the Dog River area compiled, in part, *from* unpublished maps of Platinum Group Metals Ltd.

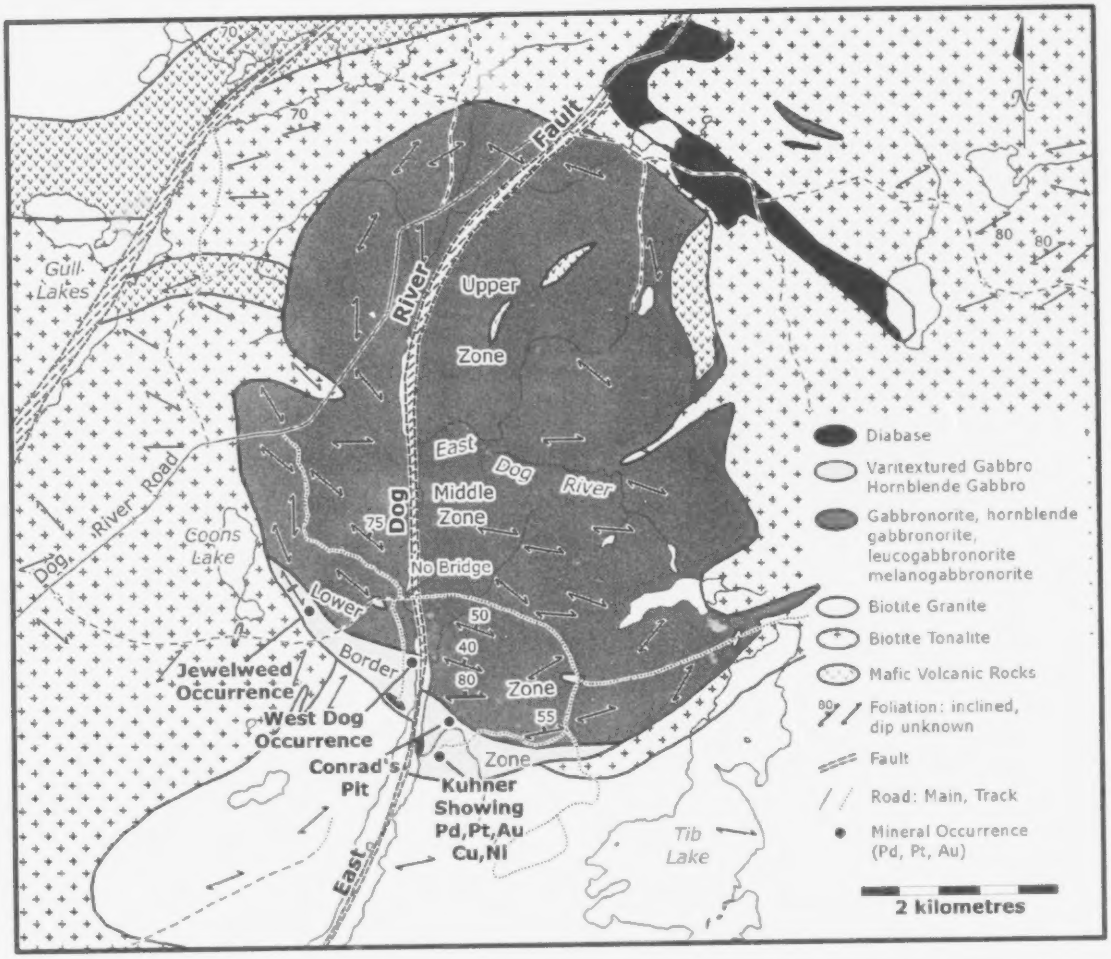
70
70
Fault
Gull Lakes
River
Upper
Zone
N
80
80
Dog River Road
East
Dog
River
Dog
Middle
Zone
75
Coons Lake
No Bridge
Lower
Border
Zone
50
40
80
55
Zone
Jewelweed Occurrence
West Dog Occurrence
Conrad's Pit
Kuhner Showing Pd,Pt,Au Cu,Ni
East
Tib Lake
Diabase
Varitextured Gabbro Hornblende Gabbro
Gabbronorite, hornblende gabbronorite, leucogabbronorite melanogabbronorite
Biotite Granite
Biotite Tonalite
Mafic Volcanic Rocks
80
Foliation: inclined, dip unknown
Fault
Road: Main, Track
Mineral Occurrence (Pd, Pt, Au)
2 kilometres

Figure 15.4. Geology of the Tib Lake area compiled, in part, *from* Smith and Sutcliffe (1987) and *from* Peredery (2000).

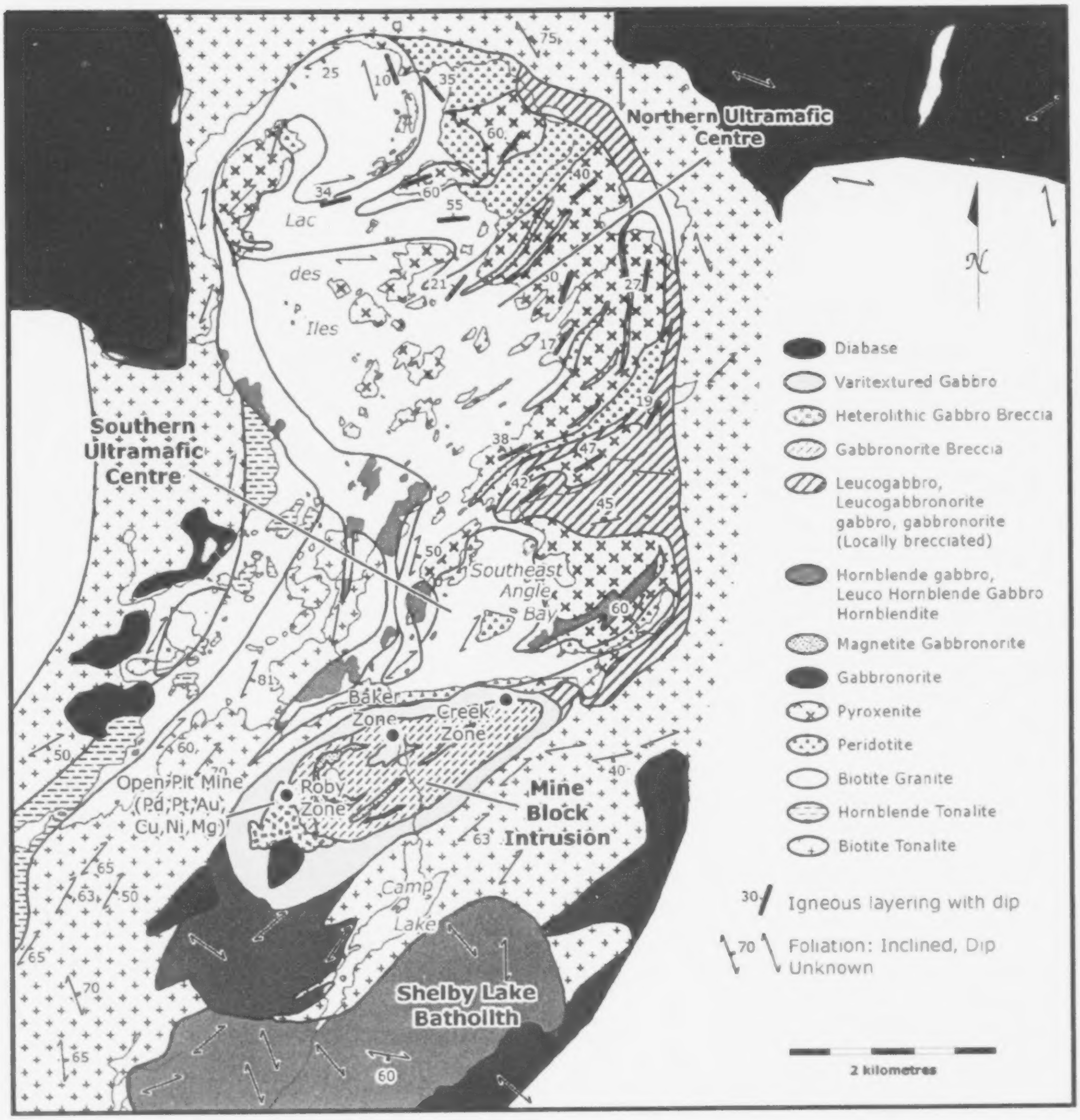
Northern Ultramafic Centre
Lac
des
Iles
Southern Ultramafic Centre
Southeast Angle Bay
Baker Zone
Creek Zone
Roby Zone
Open Pit Mine (Pd,Pt,Au, Cu,Ni,Mg)
Mine Block Intrusion
Camp Lake
Shelby Lake Batholith
N
Diabase
Varitextured Gabbro
Heterolithic Gabbro Breccia
Gabbronorite Breccia
Leucogabbro, Leucogabbronorite gabbro, gabbronorite (Locally brecciated)
Hornblende gabbro, Leuco Hornblende Gabbro Hornblendite
Magnetite Gabbronorite
Gabbronorite
Pyroxenite
Peridotite
Biotite Granite
Hornblende Tonalite
Biotite Tonalite
30 Igneous layering with dip
70 Foliation: Inclined, Dip Unknown
2 kilometres
75
25
10
35
60
34
60
55
40
21
30
27
17
19
38
47
42
45
50
60
81
50
60
70
40
63
65
63
50
65
70
65
60

Figure 15.5. Geology of the Lac des Iles complex compiled, in part, *from* Sutcliffe and Sweeny (1986) and *from* unpublished maps by North American Palladium Ltd.

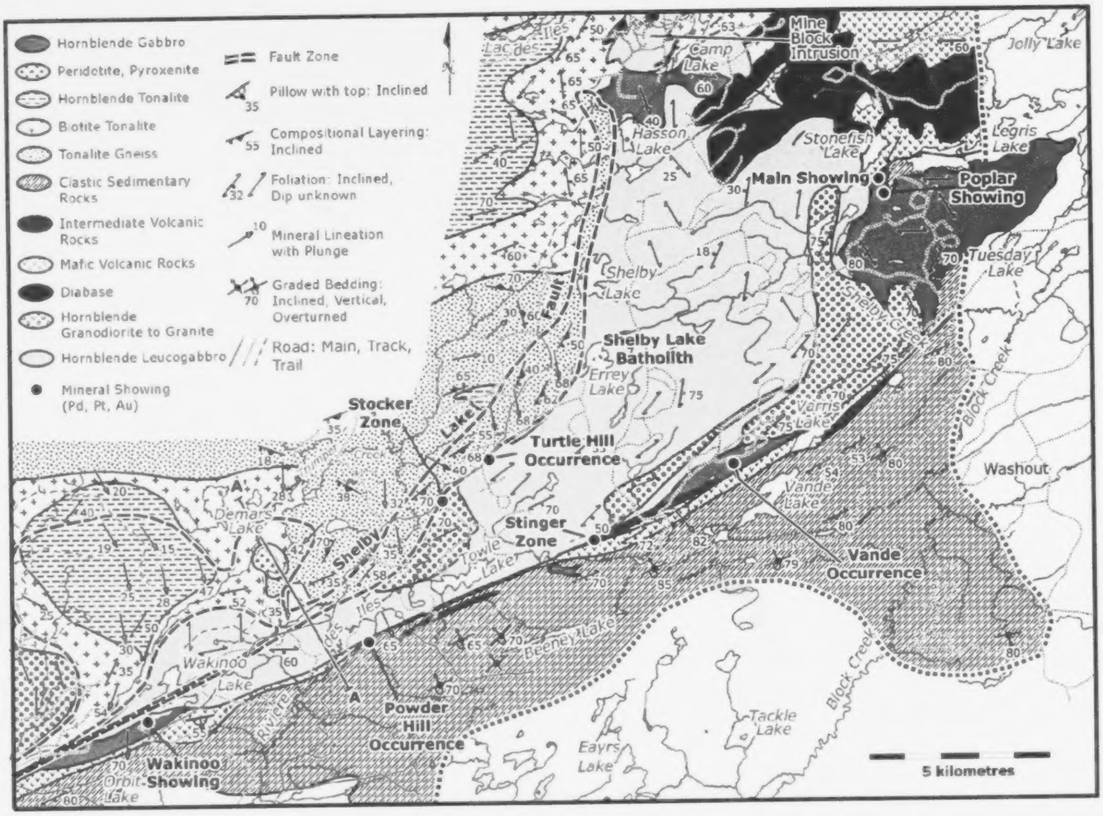
Hornblende Gabbro
Peridotite, Pyroxenite
Hornblende Tonalite
Biotite Tonalite
Tonalite Gneiss
Clastic Sedimentary Rocks
Intermediate Volcanic Rocks
Mafic Volcanic Rocks
Diabase
Hornblende Granodiorite to Granite
Hornblende Leucogabbro
Mineral Showing (Pd, Pt, Au)
Fault Zone
Pillow with top: Inclined
Compositional Layering: Inclined
Foliation: Inclined, Dip unknown
Mineral Lineation with Plunge
Graded Bedding: Inclined, Vertical, Overturned
Road: Main, Track, Trail
Mine Block Intrusion
Camp Lake
Hasson Lake
Stonefish Lake
Main Showing
Poplar Showing
Jolly Lake
Legris Lake
Tuesday Lake
Shelby Lake
Shelby Lake Batholith
Errey Lake
Stocker Zone
Turtle Hill Occurrence
Stinger Zone
Varris Lake
Vande Lake
Vande Occurrence
Washout
Demars Lake
Towle Lake
Beeney Lake
Wakinoo Lake
Powder Hill Occurrence
Wakinoo Showing
Orbit Lake
Eayrs Lake
Tackle Lake
Block Creek
Shelby Creek
Lac des Iles
Rivière
5 kilometres
A
A'

Figure 15.6. Geology of the Shelby Lake batholith compiled, in part, from Pettigrew and Hattori (2001) and unpublished maps by Platinum Group Metals Ltd.

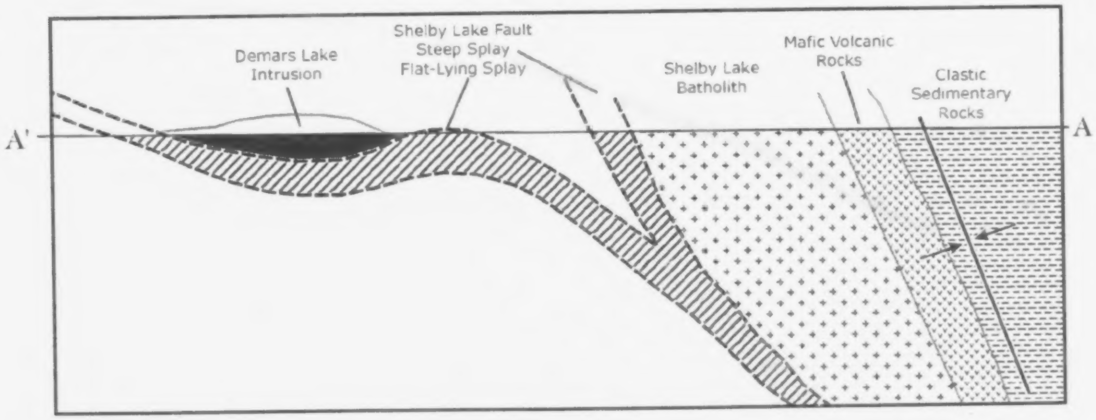
Demars Lake Intrusion
Shelby Lake Fault
Steep Splay
Flat-Lying Splay
Shelby Lake Batholith
Mafic Volcanic Rocks
Clastic Sedimentary Rocks
A'
A

Figure 15.7. Vertical cross-section of the Shelby Lake batholith at Demars Lake (see trace of cross-section A–A′ on Figure 15.6). Vertical distances are not to scale.

16. Project Unit 03-009. Reconnaissance Study of the Geology and Mineral Potential of the Eastern Tomiko Terrane, Grenville Province

R.M. Easton[1]

[1]Precambrian Geoscience Section, Ontario Geological Survey

INTRODUCTION

The Broken Hill lead-zinc-silver orebody, located near the border between the states of New South Wales and Southern Australia, has produced over 180 million tonnes of ore from 3 main mines since 1883. Other deposit types present include copper and cobalt associated with iron formation, stratabound tungsten-base metal deposits, and various vein-type deposits (e.g., Stevens, Barnes and Forbes 1990). Easton (2001) provided an overview of Broken Hill geology and discussed the validity of previous suggestions that parts of the Central Gneiss Belt of the Grenville Province (Figure 16.1) might host Broken Hill-type zinc-lead mineralization. These previous suggestions were based largely on 3 points of comparison, namely 1) the Paleoproterozoic (~1800 Ma) age of the rocks; 2) the high-metamorphic grade of the Broken Hill deposit (granulite facies); and 3) the occurrence of mineralization in a metasedimentary (paragneiss)-dominated sequence (*see* Easton 2001 for details). Determination of more precise target areas for exploration in Ontario has been hampered, in part, by the lack of detailed (less than 1:250 000-scale) mapping within the Central Gneiss Belt. Nonetheless, Easton (2001) identified several potential target areas, the most promising of which was the Tomiko terrane (*see* Figure 16.1). The purpose of this six-week reconnaissance study was to determine if Tomiko terrane is indeed a favourable host for Broken Hill-type zinc-lead mineralization, to collect samples for geochronology, and to determine if additional detailed field study is warranted.

GEOLOGY

Previous Work

Tomiko terrane (*see* Figure 16.1) is located northeast of North Bay, and is bounded to the west by Highway 11, to the east by the Ottawa River, and to the south by Highway 17. It was defined by Easton (1988), and further distinguished from other Central Gneiss Belt terranes and domains in Easton (1992). Reconnaissance mapping by Lumbers (1971a, 1971b, 1971c, 1976) exists for this terrane, along with detailed mapping by Moore (1976) focussing on parts of Butler, Antoine and Olrig townships.

Tomiko terrane is known to contain Archean rocks overlain by a Paleo- to Mesoproterozoic metasedimentary sequence that contains quartz arenite, calc-silicate rocks and, locally, magnetite-quartz iron formation (e.g., Easton 1992; Holmden and Dickin 1995). Moore (1976) also described sulphide-rich horizons within part of the stratigraphy. Quartz arenite from the terrane, collected on Highway 533 near Timber Lake, has yielded a restricted zircon population dated at 1687±20 Ma, interpreted as a

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Summary of Field Work and Other Activities 2003,
Ontario Geological Survey, Open File Report 6120, p.16-1 to 16-25.

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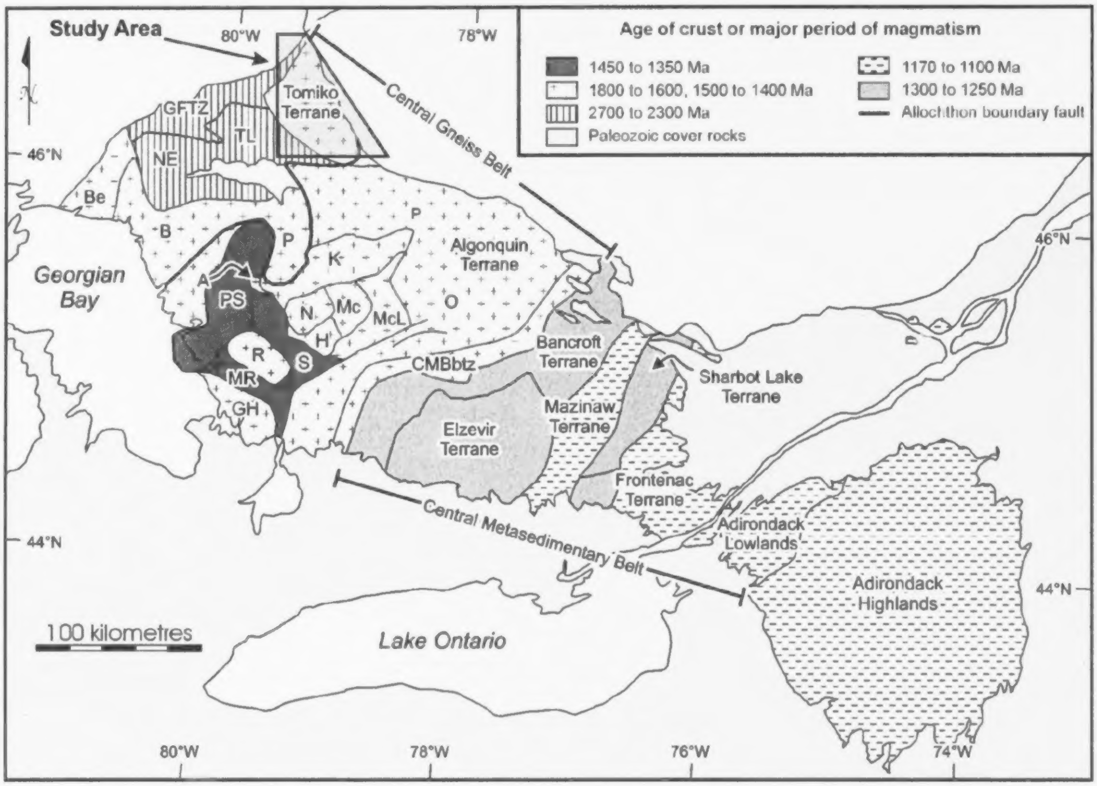
1989). It has been suggested that the restricted zircon population could be indicative of a volcaniclastic, rather than an epiclastic, unit. This single age, however, falls in the same range as that of the Willyama Supergroup, which hosts the Broken Hill orebodies. Peak metamorphic conditions in Tomiko terrane may be in the 5 to 7 kilobars range for pressure, rather than the 10 kilobars range typical of most of the Central Gneiss Belt, and 650 to 725°C for temperature. It should be noted that these conditions reflect Grenville metamorphism, which would have overprinted any early metamorphic assemblage. Moore (1976) provided textural evidence of a two-stage metamorphic evolution in parts of this terrane.


Study Area
80°W
78°W
N
Age of crust or major period of magmatism
1450 to 1350 Ma
1800 to 1600, 1500 to 1400 Ma
2700 to 2300 Ma
Paleozoic cover rocks
1170 to 1100 Ma
1300 to 1250 Ma
Allochthon boundary fault
Tomiko Terrane
Central Gneiss Belt
GFTZ
TL
NE
46°N
Be
B
P
K
Algonquin Terrane
Georgian Bay
A
PS
N
Mc
McL
O
H
R
S
MR
GH
CMBbtz
Bancroft Terrane
Sharbot Lake Terrane
Mazinaw Terrane
Elzevir Terrane
Frontenac Terrane
Adirondack Lowlands
Adirondack Highlands
Central Metasedimentary Belt
44°N
100 kilometres
Lake Ontario
76°W
74°W

Abbreviations

A	**Ahmic Domain**
B	**Britt Domain**
Be	**Beaverstone Domain** (part of Killarney magmatic belt)
CMBbtz	**Central Metasedimentary Belt boundary thrust zone**
GFTZ	**Grenville Front Tectonic Zone**
GH	**Go Home Domain**
H	**Huntsville Domain**
K	**Kiosk Domain**
M	**Muskoka**
Mc	**McCraney Domain**
McL	**McClintock Domain**
MR	**Moon River Domain**
N	**Novar Domain**
NE	**Nepewassi Domain**
O	**Openongo Domain**
P	**Powassan Domain**
PS	**Parry Sound Domain**
R	**Rosseau Domain**
S	**Seguin Domain**
SD	**Shawanaga Domain**
TL	**Tilden Lake Domain**

Figure 16.1. Tectonic subdivisions of the Grenville Province (*modified from* Easton 1992).

New Results

INTRODUCTION

Work focussed on a 2200 km^2 area covered by National Topographic System (NTS) 1:50 000 sheets 31 L/6, 31 L/7, 31 L/11 and 31 L/14 (Figure 16.2). Areas specifically targeted for study included quartzite and muscovite-rich rocks in Clarkson and McAuslan townships, a previously reported marble and sulphide zone near Miners Lake (Moore 1976), and kyanite-bearing rocks near Crocan and Cahill lakes.

Moderate to thick glacial cover covers most of the map area. The most informative bedrock exposures are commonly found along recent logging roads where the overburden has been removed temporarily. Such exposures typically are overgrown or covered within a few years after logging.

Highlights of the mapping program include

- the discovery of the presence of boron-rich and manganese-rich rocks in association with the magnetite-chert iron formation in northern Tomiko terrane
- the discovery of an orthopyroxene hornblendite body in Jocko Township. These rocks are 2475 Ma in age and are common in Street, Henry and Loughrin townships east of Sudbury (Easton 2002b)
- the discovery of a weakly metamorphosed, diatreme-like, breccia, exposed on Highway 63 in French Township
- the identification of a new lobe of the Mulock granite that covers at least 25 km^2 in western Lockhart and Garrow townships
- the identification of several granite bodies within northern Tomiko terrane that were previously mapped as feldspathic metasedimentary rocks
- the recognition of possible "basement" rocks infolded with the metasedimentary gneisses, particularly in northern Tomiko terrane
- the identification of a migmatite front between northern and southern Tomiko terrane
- the identification of at least 3 metamorphic events affecting the supracrustal rocks in Tomiko terrane, with the intensity of the 2 latest events increasing to the southeast
- the recognition that the metasedimentary succession contains less quartz arenite and more amphibolite than shown on existing maps

TECTONIC FRAMEWORK

Tomiko terrane is bounded to the north by the Grenville Front tectonic zone (*see* Figure 16.1), which in this area consists mainly of tectonized Archean rocks of the Red Cedar Lake gneiss. To the east, Tomiko terrane continues across the Ottawa River into Quebec. It is bounded to the west by Archean rocks of the Tilden Lake domain (*see* Figure 16.1). To the south, it is structurally overlain by the Bonfield and Mattawan domains (*new terms*) of the Algonquin terrane (*see* Figure 16.1, Table 16.1). The Allochthon Boundary Thrust marks the boundary between Tomiko and Algonquin terrane, and separates rocks with links to the North American craton from tectonically transported rocks to the south (e.g., Carr et al. 2000). Table 16.1 summarizes the key features of these domains and terranes.

Tomiko terrane can be divided into a western domain dominated by gneisses of Archean and Paleoproterozoic age intruded by the Mulock gneissic granite, and an eastern domain dominated by supracrustal rocks of likely Paleoproterozoic age. Fieldwork focussed on the eastern domain, although rocks of the western Tomiko, Bonfield and Mattawan domains were studied for comparative purposes.

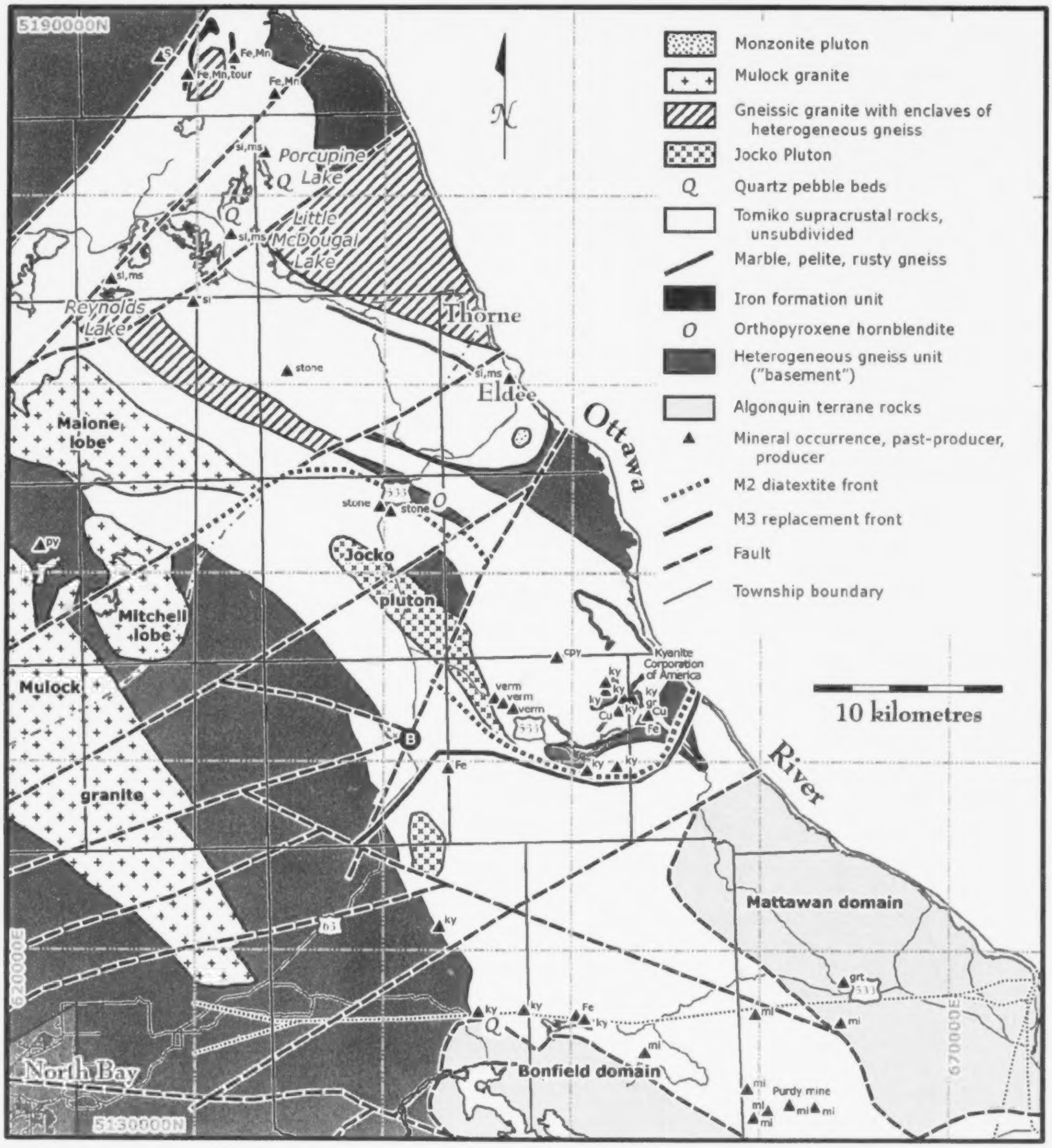

5190000N
5130000N
620000E
670000E
N
Monzonite pluton
Mulock granite
Gneissic granite with enclaves of heterogeneous gneiss
Jocko Pluton
Q Quartz pebble beds
Tomiko supracrustal rocks, unsubdivided
Marble, pelite, rusty gneiss
Iron formation unit
O Orthopyroxene hornblendite
Heterogeneous gneiss unit ("basement")
Algonquin terrane rocks
Mineral occurrence, past-producer, producer
M2 diatextite front
M3 replacement front
Fault
Township boundary
10 kilometres
Porcupine Lake
Little McDougal Lake
Reynolds Lake
Thorne
Eldee
Ottawa River
Malone lobe
Mitchell lobe
Mulock granite
Jocko pluton
Kyanite Corporation of America
Mattawan domain
Bonfield domain
North Bay
Purdy mine
B
533
63
S
Fe,Mn
Fe,Mn,tour
si,ms
si
stone
py
cpy
verm
ky
gr
Cu
Fe
grt
mi

Figure 16.2. Geologic sketch map of Tomiko terrane, showing location of mineral occurrences, past-producers and producers, including new occurrences reported in this study. Only the distribution of key geological units and structures are shown. Abbreviations: cpy, chalcopyrite; Cu, copper; Fe, iron; gr, graphite; grt, garnet; ky, kyanite; mi, mica; Mn, manganese; ms, muscovite; py, pyrite; S, sulphides; si, silica; tour, tourmaline; verm, vermiculite.

Table 16.1. Major tectonic subdivisions of the Grenville Province in the vicinity of North Bay.

Terrane	Domain	Major Rock Types	Age
Laurentian margin			
Grenville Front tectonic zone	Eastern segment	Granular and block gneiss of the Red Cedar Lake gneiss, granodiorite gneiss of the Ingall Lake pluton, minor pegmatite (Archean in age). Metamorphosed Sudbury diabase dikes.	Archean with Grenville metamorphic overprint
	Tilden Lake	Heterogeneous mafic to intermediate composition gneisses intruded by younger monzogranite plutons, minor paragneiss, amphibolite. Metamorphosed Sudbury dikes.	Archean gneisses with 1270 to 1235 Ma mafic and felsic metaplutonic rocks
Tomiko	Western	Heterogeneous mafic to intermediate composition gneisses intruded by younger monzogranite plutons (Mulock granite), minor paragneiss, amphibolite. Metamorphosed Sudbury diabase dikes.	Archean to Paleoproterozoic gneisses, cut by 1270 to 1235 Ma mafic and felsic metaplutonic rocks
	Eastern	Quartzose and feldspathic metasedimenary rocks with minor calc-silicate gneiss, iron formation, marble and interlayered felsite, dacitic gneisses, and amphibolite (sills, flows and/or volcaniclastic rocks) to mafic sills or volcanic flows, overlying a possible basement complex consisting of heterogenous mafic to intermediate composition gneisses. Intruded by at least 3 ages of felsic to intermediate metaplutonic rocks. Metamorphosed Sudbury diabase dikes yet to be positively identified.	Paleoproterozoic to Mesoproterozoic. Mulock granite ($1244^{+4}/_{-3}$ Ma) probably cuts the metasedimentary sequence
South of the Allochthon Boundary Thrust and the Laurentian Margin			
Algonquin	Bonfield	Quartz monzonite to monzogranite plutons, minor amphibolite, marble, granitic pegmatites, meta-anorthosite and related mafic rocks (north of Mattawa fault). Coronitic metagabbro locally present.	Mesoproterozoic 1450 to 1270 Ma (felsic metaplutonic rocks)
	Mattawan	Quartz monzonite plutons, intermediate composition gneisses, pseudoecologite pods and layers associated with meta-anorthosite and related mafic rocks (north of Mattawa fault). Coronitic metagabbro locally present.	Paleoproterozoic to Mesoproterozoic

STRUCTURE

As illustrated in Figure 16.3, eastern Tomiko terrane is cut by at least 4 shear zones, trending 50 to 60°, located roughly 8 to 12 km apart. For the purpose of clarity, minor offsets of the shear zones by faults related to the Ottawa–Temiskaming graben are not shown in Figure 16.3. A variety of physiographic and geological changes occur across these shear zones as illustrated in Figure 16.3. Physiographic changes include a sudden increase in topography and outcrop abundance on the hanging wall side of the shear zones, as well as abrupt changes in the direction of major streams and rivers along the trace of the shear zones. In addition, the shear zones are generally marked by topographic lows; it is probably no coincidence that the location of a natural gas pipeline in the area closely parallels the trace of one of these zones. Where exposed, the shear zones consist of porphyroclastic or straight gneisses, or both. Geological changes across the shear zones are indicated in Figure 16.3, and include changes in metamorphism (*see* "Metamorphism"), fold interference style, and orientation of major geological units (e.g., Jocko pluton, *see* Figure 16.3). The shear zones parallel the orientation of the Grenville Front, and appear to affect all major Precambrian rock units in the terrane. It is likely that these are Grenville Front parallel thrust faults that have exhumed progressively deeper structural levels to the south. If so, then the shear zones likely formed between 1040 and 990 Ma, during the development of the Grenville Front tectonic zone (Carr et al. 2000). Due to thick drift, it has not been possible to ascertain if the contact between possible basement rocks and the metasedimentary gneiss package—characteristic of Tomiko terrane along Opimika Creek—is an unconformity, or if it is a shear zone that parallels Opimika Creek (*see* Figure 16.3).

METAMORPHISM

Both the intensity and spatial distribution of several metamorphic events play a critical role both in the appearance of the major rock units within the Tomiko terrane (compare Photos 16.1a and 16.1b) and the ability to perform stratigraphic analysis. In brief, the best preserved and least deformed rocks are located northeast of Highway 63.

At least 4 regional metamorphic events are present in the area, as summarized in Table 16.2. M_0 is restricted to the heterogeneous gneisses that may represent basement to the terrane, and apart from the fact that partial melting occurred, there are no constraints on the *P–T* conditions of this event. M_1 is best preserved in the northeastern part of Tomiko terrane, and consists of early formed kyanite or sillimanite that has been largely replaced by white mica that was formed during M_2. Early formed leucosome in rocks of the metasedimentary sequence may also have developed during M_1. M_2 is manifested by the widespread development of abundant (25 to 40% of the rock) partial melt pods and layers in quartzofeldspathic gneisses of the metasedimentary sequence (*see* Photo 16.1b), and late melt (~10%) within amphibolite that is interlayered with the metasedimentary sequences. It is also likely that the muscovite-biotite-garnet-kyanite gneisses in the Timber Lake area developed during M_2. M_3 is represented by the replacement of granitic melt pods formed during M_2 by pale green kyanite and quartz assemblages (Photo 16.2). Other effects of M_3 are the replacement of early formed blue kyanite by pale green kyanite; breakdown of muscovite to form kyanite and potassium feldspar; and the development of kyanite within garnet amphibolite interlayered with the metasedimentary gneisses. M_3 may be as much a metasomatic replacement event as a regional metamorphic episode. It is also possible that M_2 and M_3 might represent a continuous event, as both events are fluid rich, and the intensity of both events increase to the southeast. It is possible that M_2 and M_3 are related to the emplacement of the Bonfield and Mattawan domains atop Tomiko terrane and the initiation of the Allochthon Boundary Thrust. As shown in Figure 16.3, different fold interference styles are also associated with each of M_1, M_2 and M_3.

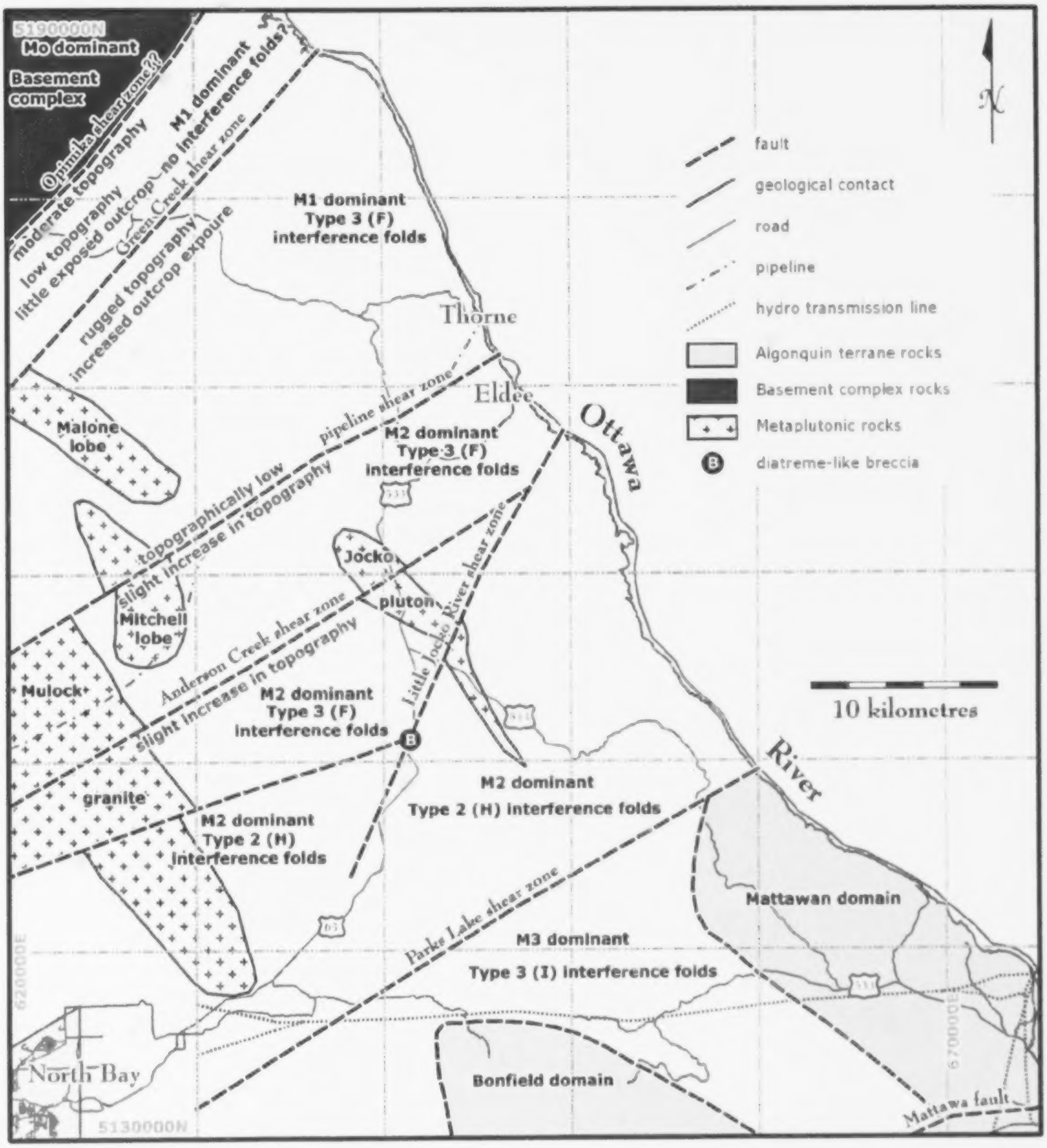

5190000N
Mo dominant
Basement complex
Opimika shear zone??
M1 dominant no interference folds?
moderate topography
low topography
little exposed outcrop
Green Creek shear zone
rugged topography
increased outcrop expoure
M1 dominant
Type 3 (F)
interference folds
Thorne
Eldee
Ottawa
pipeline shear zone
M2 dominant
Type 3 (F)
interference folds
Malone lobe
topographically low
slight increase in topography
Jocko pluton
Little Jocko River shear zone
Mitchell lobe
Anderson Creek shear zone
slight increase in topography
M2 dominant
Type 3 (F)
interference folds
Mulock granite
M2 dominant
Type 2 (H)
interference folds
M2 dominant
Type 2 (H) interference folds
River
Parks Lake shear zone
M3 dominant
Type 3 (I) interference folds
Mattawan domain
Bonfield domain
North Bay
Mattawa fault
5130000N
620000E
670000E
533
63
N
fault
geological contact
road
pipeline
hydro transmission line
Algonquin terrane rocks
Basement complex rocks
Metaplutonic rocks
B diatreme-like breccia
10 kilometres

Figure 16.3. Sketch map showing location of major shear zones in eastern Tomiko terrane, as well as the geological and physiographic changes across the zones. Slight offsets of the shear zones by Ottawa graben faults are not shown for clarity. Pluton contacts simplified from Figure 16.2. Fold intereference types *from* Ramsay and Huber (1987, p.484).

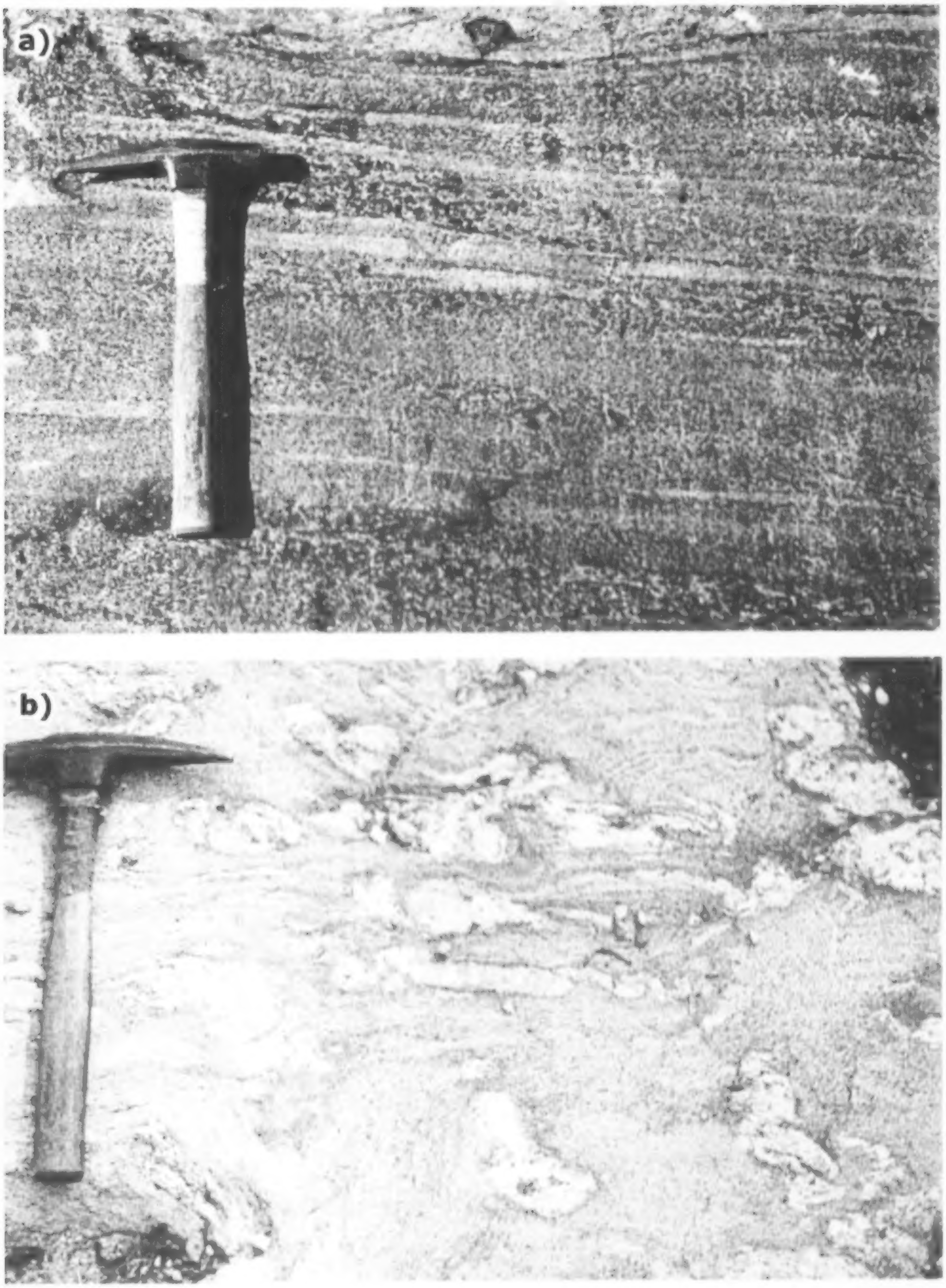


Photo 16.1. **a)** Upper photograph shows typical medium-layered feldspathic gneiss of the metasedimentary gneiss package in the area where M_1 is dominant (UTM NAD 83, Zone 17, 640207E 5169958N). **b)** Lower photograph shows typical "juicy" migmatitic gneiss (diatextite) derived from the same medium-layered feldspathic gneiss as shown in the upper photograph, but from the area where M_2 is dominant (UTM NAD 83, Zone 17, 651170E 5149455N). Hammer handle is 30 cm long.

Gresens (1971) described kyanite-quartz segregations from New Mexico that are hosted in a Precambrian metavolcanic and metasedimentary sequence lithologically similar to that preserved in the southeastern Tomiko terrane. Gresens (1971) suggested that the segregations formed by metasomatic reaction between the metarhyolite host rocks and acidic fluids transported along shear zones, with the primary reaction being

$$\text{potassium feldspar} + H^+ = \text{kyanite} + \text{quartz} + H_2O + K^+$$

with a secondary reaction

$$\text{kyanite} + \text{quartz} + H_2O + K^+ = \text{muscovite} + H^+$$

occurring as a result of increasing K in the fluid with increased leaching. As long as the initial fluid was highly acidic (i.e., ~5% HCl), fluid volumes necessary for the process were reasonable. Gresens (1971) likened this fluid to a high temperature equivalent of an acidic hydrothermal fluid. The process suggested by Gresens (1971) is a likely explanation for the development of the segregations in Tomiko terrane, and may also explain the origin of the kyanite rocks in the Timber Lake area (*see* discussion under "Kyanite"). The presence of acidic fluids late in the geological evolution of Tomiko terrane has implications for mineralization, as discussed later in this article under "Mineral Potential".

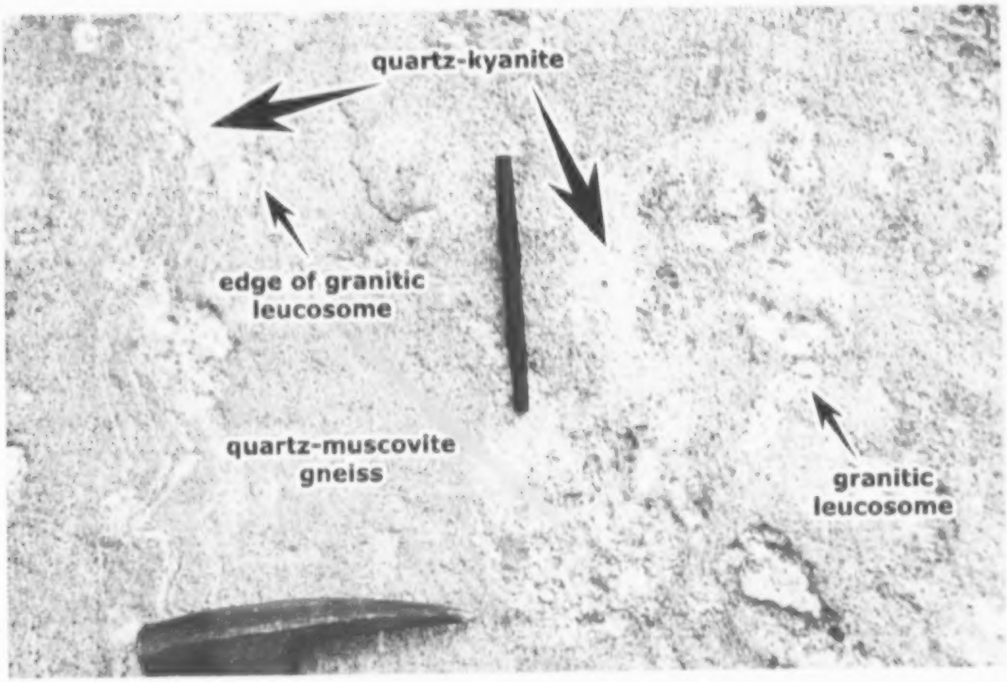


Photo 16.2. Photograph showing partial replacement of a pod of granitic leucosome formed during M_2 in a quartzose gneiss by pale green kyanite and quartz formed during M_3. Outcrop on a logging road south of Timber Lake. (UTM NAD 83, Zone 17, 651330E 5149095N). Pen is 13.5 cm long.

Table 16.2. Summary of major metamorphic events present in Tomiko terrane.

Event	Rock Unit	Description and Estimated *P-T* Conditions	Where Dominant. Inferred Age	Comment
M_3	Muscovitic and quartzitic gneisses, calc-silicate and mafic gneisses	Replacement of M_2 leucosome by kyanite-quartz (*see* Photo 16.2), development of kyanite in some garnet amphibolite units. Bathozone 6, >640°C and >7 kilobars.	South and west of Highway 533. Between 1040 and 995 Ma?	M_2 muscovite locally breaks down forming kyanite-potassium feldspar, related to metasomatic fluids?
M_2	Muscovitic and quartzitic gneisses, calc-silicate and mafic gneisses	Development of abundant (>25% in metasedimentary gneisses, *see* Photo 16.1b) granitic leucosome and muscovite. Bathozone 5 or 6, <640°C but >5 kilobars. Moore (1976) estimated >8.5 kilobars and ~725°C. Anovitz and Essene (1990) estimated 8.6 to 9.3 kilobars and >600°C.	Southeast of Highway 63, south and west of Highway 533. Between 1040 and 1180 Ma or 1040 and 995 Ma?	Leucosome is commonly pod-like
M_1	Muscovitic and quartzitic gneisses (*see* Photo 16.1a)	Development of kyanite or sillimanite in metasedimentary gneisses. Unknown, but likely 600 to 700°C and >5 kilobars. Anovitz and Essene (1990) estimated >6.6 kilobars and <760°C.	Northeast of Highway 63. Between 1400 and 1750 Ma?	Poorly preserved, as early formed minerals are partly or wholly replaced by white mica, minor partial melting locally, early leucosome is thin (<3 cm thick), layer parallel?
M_0	Heterogeneous gneisses (structural or depositional basement)	Migmatization of ortho- and paragneisses. Unknown, other than that temperatures were high enough for partial melting to occur.	Restricted to exposures of basement in terrane. Archean or Paleoproterozoic	

ROCK UNITS

The key features of the rock units outlined by this study in eastern Tomiko terrane are summarized in Table 16.3. What follows is a description of the more pertinent features with respect to regional stratigraphy and mineral potential.

Heterogeneous Gneisses ("Basement" Complex)

An extensive area underlain by a unit of heterogeneous gneiss (Photo 16.3) lies west and north of the main package of supracrustal rocks (*see* Figure 16.2), as well as being infolded with the supracrustal rocks. In addition, some of the younger granitoid intrusions in eastern Tomiko terrane incorporate screens of these heterogeneous gneisses. An orthopyroxene hornblendite body was located near the contact between an area of heterogeneous gneisses and the Tomiko supracrustal rocks in Jocko Township, and appears to be hosted solely in the heterogeneous gneiss unit. If this body is the same age as orthopyroxene hornblendite bodies in the Sudbury area, that is, approximately 2475 Ma (Easton 2002b), then some, if not all, of the heterogeneous gneisses are Archean. Holmden and Dickin (1995) reported a Nd/Sm model age of 2570 Ma from the heterogeneous gneiss unit near the eastern margin of the Mulock granite, again, suggesting that this rock unit is Archean.

The heterogeneous gneisses may represent basement to the Tomiko supracrustal rocks, although it is not known if this basement is structural or depositional. If the heterogeneous gneisses are largely Archean, then it is unlikely that the heterogeneous gneisses are depositional basement, because of the lack of Archean detrital zircons and Archean Nd/Sm ages within the Tomiko supracrustal rocks (Krogh 1989; Holmden and Dickin 1995). The significant difference in the Nd/Sm ages of the Mulock granite located in the western Tomiko terrane and the Jocko pluton hosted by the Tomiko supracrustal rocks (2360 and 1770 Ma, respectively, Holmden and Dickin (1995)), may also be an indication that the heterogeneous gneisses are structural, not depositional, basement to the supracrustal rocks.

Tomiko Supracrustal Rocks

The term "Tomiko supracrustal rocks" is used in this report as an overarching term encompassing a variety of rock types, largely of metasedimentary origin, present in eastern Tomiko terrane. Rocks belonging to this package are highlighted in Table 16.3, and the stratigraphy of these units is described under "Stratigraphy".

The most common units consist of calc-silicate gneiss, quartzite (metaquartz arenite) and quartz-muscovite gneiss, and feldspathic gneiss. True quartz arenite is largely confined to the northeastern part of the terrane and consists of 2 types: 1) a massive, locally thick-bedded, variety; and 2) a thin- to medium-bedded variety that locally contains relict cross-bedding. The latter type is more common.

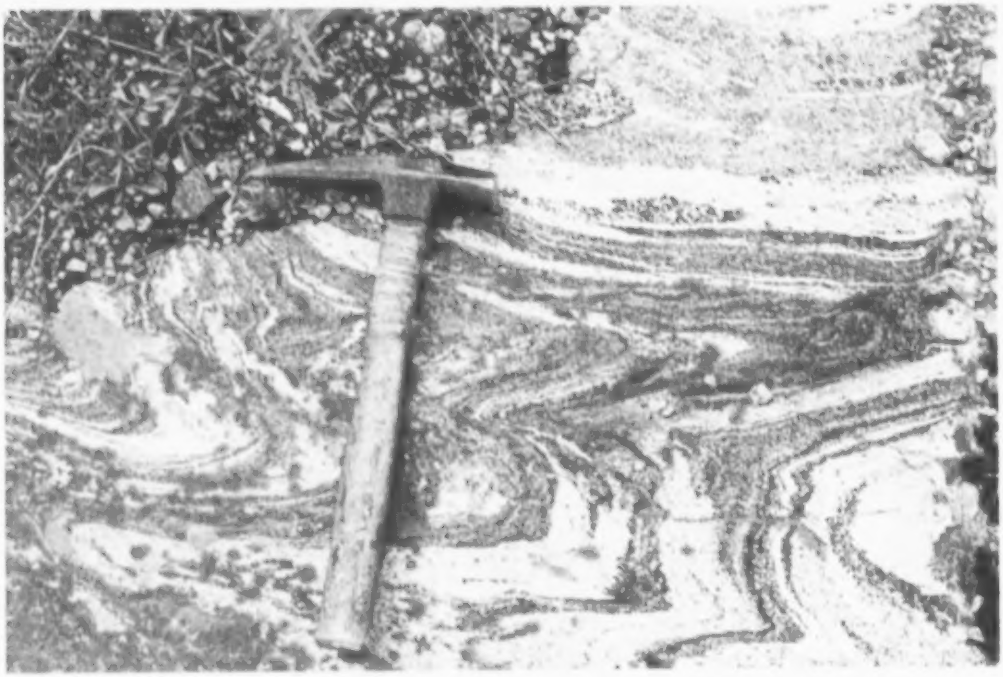


Photo 16.3. Typical gneisses of the basement complex within Tomiko terrane (UTM NAD 83, Zone 17, 651238E 5162733N). Hammer handle is 30 cm long.

Table 16.3. Table of major rock units in Tomiko terrane. Neodymium–samarium model ages from Holmden and Dickin (1995), other ages from Baer (1980), Lumbers et al. (1991), and Krogh (1989). ***Highlighted*** units are part of the Tomiko supracrustal rock package. To faciliate comparison with existing maps, the relevant unit codes from those maps are indicated.

Rock unit	Description	Age or Age Range	Map Unit (Lumbers 1971a, b, c, 1976)
Late diabase dikes	Easterly trend, Grenville swarm	circa 590 Ma	unit 11, or 15, or 29
Diatreme-like breccia	Exotic mafic fragments with high magnetic susceptibility in a medium-grained monzonite matrix, forms ovoid body that cuts migmatitic gneisses at a high angle to gneissosity (*see* Photo 16.4)	circa 1050 Ma? (weakly metamorphosed, may be related in age to the 1050 Ma Sullivan Island alkalic complex on Ottawa River)	not reported
Late granitic rocks	Feldspar-phyric quartz syenite to quartz monzonite	circa 1050 Ma? (margins are weakly metamorphosed)	unit 26d
Mulock granite and related rocks	Pink, gneisic monzogranite, feldspar-megacrystic gneissic monzogranite to augen monzogranite gneiss	1244^{+4}_{-3} Ma (U/Pb zircon), Nd/Sm model age of 2360 Ma	unit 26a or 7c
Jocko pluton and related rocks ◆	Buff or pink, streaky, biotite-hornblende monzonite to monzogranite gneiss	>1137±173 Ma (Rb/Sr) but <1770 Ma (Nd/Sm age)	unit 21a, 21b, or 7c
Grey gneiss ◆	Medium-grained, granodiorite gneiss, locally with relict fragments and feldspar megacrysts (possible metavolcanic)	Nd/Sm ages of 1970 to 2200 Ma, maximum age of unit	unit 16 or 17
Amphibolite	Dark green, amphibolite and garnet amphibolite, increases in abundance and degree of migmatization to the southeast (possible metavolcanic and/or sills)		unit 19 and 24 or 5
Felsite	Pink, thin- to medium-layered, fine-grained granitic gneiss (metavolcanic?)	Nd/Sm age of 1900 Ma, maximum age of unit	unit 3 or 18
Feldspathic gneisses	Thin- to medium-layered, muscovite-potassium feldspar-quartz gneiss, weakly to strongly migmatitic, muscovite clots give rock a speckled or spotted appearance	Nd/Sm ages of 1910 to 2160 Ma, maximum age of unit	unit 3 or 18 or 17
Quartzitic and quartz-muscovite gneisses ◆	Thin- to thick-layered metamorphosed quartz arenite and arenite	1687±20 Ma (U/Pb), Nd/Sm ages of 1920 to 2340 Ma	unit 18a, 18c or 4
Pelitic gneisses	Fine-grained, thin-layered, metasiltstone to biotite-kyanite-garnet gneiss, variably migmatitic (may be of hydrothermal origin?)		unit 18c or 4b or 4
Iron formation and related rocks	Magnetite-chert rock and coarse-grained hornblende gneisses with high (35 to 500) magnetic susceptibility, also rusty-weathering pyrrhotite gneiss		unit 13 and 19 and 18d
Marble	Massive, grey, medium- to coarse-grained calcite marble		unit 20 or 6
Calc-silicate gneisses	Grey to grey-green, biotite-rich, medium-layered, quartz-plagioclase gneiss, generally weakly migmatitic		unit 16, 19 or unit 5
Orthopyroxene hornblendite	Bronzite megacrysts hosted in a fine-grained, acicular, dark green, amphibole matrix; hosted only in basement complex?	circa 2475 Ma?	not reported
Heterogeneous gneisses ("basement complex")	Compositionally heterogeneous, thin- to medium-layered, mafic to intermediate (amphibolite, diorite, granodiorite) gneisses, ranging from complexely folded to highly flattened (*see* Photo 16.3)	Archean (and Paleoproterozoic?), Nd/Sm model ages >2570 Ma	units 1 and 2 or 15 and 16

◆ indicates units sampled for U/Pb geochronology as part of this study.

Two types of feldspathic gneiss are present, one which may be metasedimentary in origin, the other which may be igneous (flows or sills). The feldspathic gneiss of metasedimentary origin is commonly migmatitic, regardless of location in the terrane, and contains greater than 5% muscovite. The feldspathic gneiss of igneous origin, referred to as felsite in this report, is only migmatitic in the southeast part of the map area, and contains less muscovite and quartz than the metasedimentary type. In thin section, the feldspathic gneiss and the felsite can be readily distinguished from granitoid orthogneiss, as the felsite contains more plagioclase, and possesses irregular-shaped grains of all mineral phases. In contrast, the feldspathic gneiss typically contains regular-shaped grains exhibiting 120° grain boundaries, dominated by microcline and perthite. In addition, the granitoid orthogneiss exhibits somewhat elevated magnetic susceptibility values (2 to 15) compared to the feldspathic gneisses (<1, excluding leucosome), especially near the margins of the intrusions.

Previous workers (e.g., Lumbers 1971b) have noted the presence of "iron formation" in northeastern Tomiko terrane. This unit is generally poorly exposed. Magnetite-chert rocks appear to be a minor component of this unit. Most of the "iron formation" unit consists of a coarse-grained, dense, amphibole-rich rock that shows varied magnetic character (magnetic susceptibility generally 10 to 60, locally with bands between 200 and 500). These amphibole-rich rocks are sandwiched between metapelitic rocks and marble. Moore (1976) suggested that the iron formation was correlative with pyrrhotite- and pyrite-bearing feldspathic gneiss present in the Miners Lake and Timber Lake areas, however, this correlation cannot be directly confirmed. Additional description of the iron formation unit is presented in "Mineral Potential".

As well as the felsite unit, a unit of dacitic grey gneiss is present south of Big McDougal Lake. This unit is locally fragmental in character, and may also be volcanic in origin, although it is possible that it may represent a combination of flows and sills. Near Timber Lake, the felsite unit is associated with medium-grained, dark weathering amphibolite and garnet amphibolite bodies that are different in texture and composition from the biotite-epidote-amphibole-bearing rocks typical of the calc-silicate gneisses. Again, these amphibolites may represent flows, dikes or sills. In the area dominated by M_3, both the calc-silicate gneisses and the amphibolites are metamorphosed to a medium-grained, garnet amphibolite, and the 2 types of mafic rocks can no longer be distinguished in the field. Amphibolite and calc-silicate gneisses appear to be more abundant south of Highway 63. It has yet to be determined if this is related to a north-to-south facies change in the terrane, or if it simply reflects the fact that these rocks become more resistant to weathering with increased metamorphic grade.

Intrusive Rocks

At least 3, and possibly 4, ages of intrusive rocks intrude the Tomiko supracrustal rocks. Two major suites are present, only one of which has had its age determined. A volumetrically smaller suite of penetratively deformed, buff to pink weathering, hornblendite monzonite to monzogranite, typified by the Jocko Lake pluton, is most common in the areas affected by M_2 and M_3. A volumetrically larger suite of variably deformed, commonly potassium feldspar megacrystic or porphyroblastic, monzogranite to syenogranite is typified by the Mulock granite.

The Mulock granite has yielded a U/Pb zircon age of $1244^{+4}/_{-3}$ Ma (Lumbers et al. 1991). Rocks typical of the Mulock granite occur only in the west part of the study area. Granitic rocks in the east and northeast parts of the study area (*see* Figure 16.2) tend to be finer grained than the Mulock granite and are not potassium-feldspar megacrystic, although they commonly contain flattened potassium-feldspar porphyroblasts. It is possible that these granitic rocks may be a different age than the Mulock granite.

A monzonite to syenite body located due east of the Hamlet of Eldee has an undeformed core, but does exhibit a foliation along its margins.

A weakly metamorphosed breccia is exposed along Highway 63 in French Township (Photo 16.4). It is hosted in diatextite derived from quartz-muscovite rocks of the Tomiko supracrustal rocks. The breccia body, is roughly 10 m wide and 20 m long, and consists of exotic, fine-grained, variably epidotized, mafic fragments with magnetic susceptibility between 0.5 and 2. The fragments are hosted in a medium-grained, granodioritic matrix consisting of a mixture of feldspar and quartz xenocrysts, small mafic fragments and biotite granodiorite with a magnetic susceptibility between 30 and 100. In places, the breccia resembles an intrusion breccia, but it may also resemble a diatreme. The breccia is in an area excluded from staking because of a nearby Ministry of Natural Resources fish hatchery.

STRATIGRAPHY

Moore (1976) outlined a stratigraphic sequence in southeastern Tomiko terrane (Figure 16.4). This study confirms many aspects of this earlier work, most notably the identification of metaconglomerate in the Cahill Lake area, and the correlation of the supracrustal rocks between the Timber Lake and Cahill Lake area. Moore (1976) proposed that the Antoine gneiss overlies the metasedimentary sequence, however, this unit actually consists of several rock types, including parts of the "basement" complex, as well as plagioclase-rich gneisses interlayered with the supracrustal rocks. Thus, the Antoine gneiss has a more complex stratigraphic relationship with the supracrustal rocks than envisaged by Moore (1976).

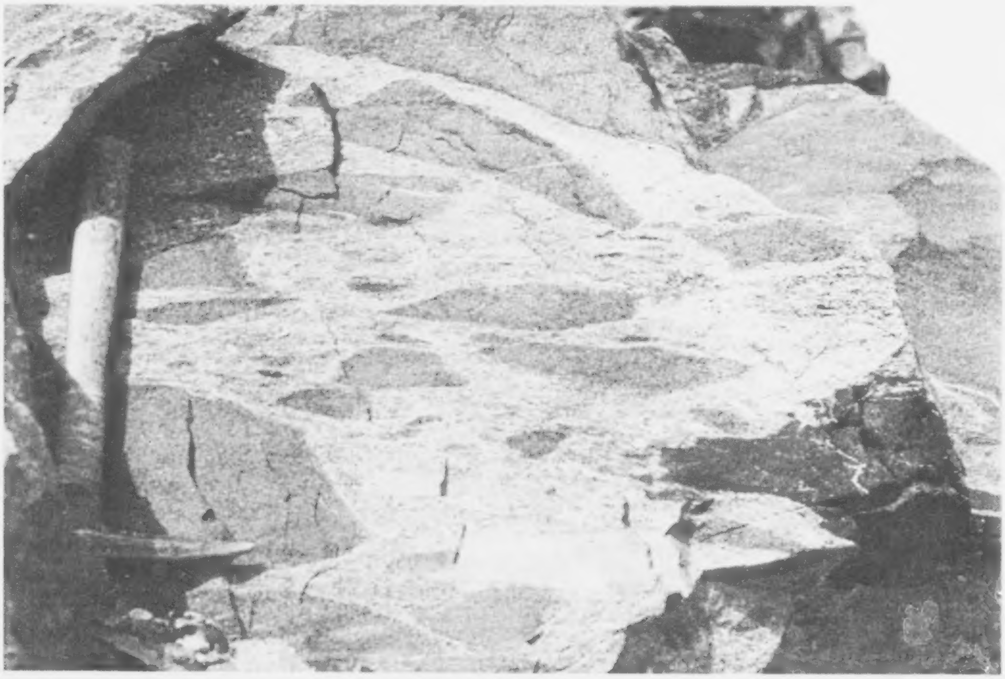


Photo 16.4. Diatreme-like breccia exposed on Highway 63 (UTM NAD 83, Zone 17, 641228E 5150937N). Hammer handle is 30 cm long.

Stratigraphic analysis is most easily accomplished in northeastern Tomiko terrane, where M_1 dominates, but becomes increasingly difficult to the southeast as metamorphic grade and fold complexity increases. North of Highway 63, cross-bedding and grading, particularly in the quartz arenite units, provides some control on facing direction. Figure 16.4 shows some of the regional variation that is present in Tomiko terrane, and is based on stratigraphic sections from Parkham and Clarkson townships and Timber Lake. In addition, Figure 16.4 shows a revised interpretation of the stratigraphic column proposed by Moore (1976) for the Timber and Cahill Lake areas.

Important features to note in Figure 16.4 are as follows:

1. Quartz arenite occurs both near the base and the top of the succession. The lower quartz arenite units are thin to medium bedded, are interlayered with calc-silicate rocks, and appear to be no

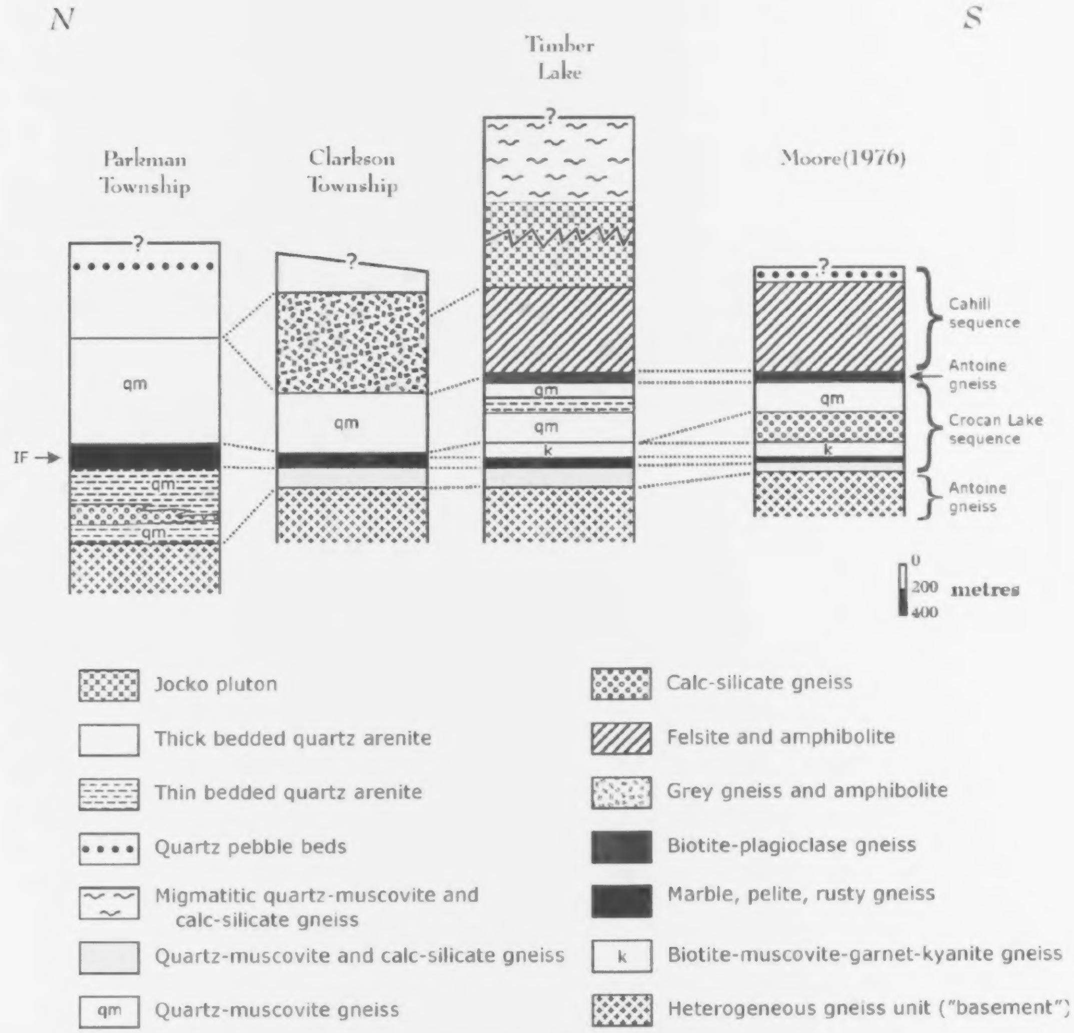

N
S
Timber Lake
Parkman Township
Clarkson Township
Moore(1976)
?
qm
k
IF
Cahill sequence
Antoine gneiss
Crocan Lake sequence
Antoine gneiss
0
200
400
metres
Jocko pluton
Thick bedded quartz arenite
Thin bedded quartz arenite
Quartz pebble beds
Migmatitic quartz-muscovite and calc-silicate gneiss
Quartz-muscovite and calc-silicate gneiss
Quartz-muscovite gneiss
Calc-silicate gneiss
Felsite and amphibolite
Grey gneiss and amphibolite
Biotite-plagioclase gneiss
Marble, pelite, rusty gneiss
Biotite-muscovite-garnet-kyanite gneiss
Heterogeneous gneiss unit ("basement")

Figure 16.4. Stratigraphic sections from north to south across Tomiko terrane. A revised interpretation of the section of Moore (1976) is shown on the left-hand side of the diagram, linking the Timber Lake and Cahill Lake areas.

more than a few hundred metres thick. In contrast, the upper quartz arenite units are medium to thick bedded, locally contain quartz pebble and cobble horizons, and may be over 500 m thick. The upper quartz arenite unit appears to thin to the south, but this may reflect preservation, rather than a true facies change.

2. Possible metavolcanic rocks and related sills first appear north of the pipeline shear zone, and are mainly dacitic. In the Timber Lake area, possible metavolcanic and related intrusive rocks are bimodal, consisting of felsite and amphibolite, and appear to be of greater thickness.
3. Although calc-silicate rocks occur at several places in the succession, they appear to be most common near the base. Generally, a thin unit of quartz-muscovite rock or quartz arenite is present immediately adjacent to the contact with rocks of the heterogeneous gneiss unit.
4. The sequence of marble, iron formation, sulphide-rich schist and metapelite appears to represent a marker horizon, at least north of Highway 63, and appears to be restricted to the lower part of the section. In Figure 16.4, it is assumed that the sulphide-rich schists and biotite-garnet-kyanite rocks in the Timber Lake area are equivalent to this horizon, an assumption that is generally consistent with the overall stratigraphic section near Timber Lake. If this assumption is incorrect, then linkage between the stratigraphy north of Highway 63 and in the Timber Lake area is problematic.
5. In all 3 areas, rocks of the heterogeneous gneiss unit appear to underlie the supracrustal rocks. The contact between the supracrustal rocks and the heterogeneous gneiss unit has not been observed in the field, but there is no evidence such as the presence of conglomerates or weathering of the underlying gneisses to indicate that it is an unconformity.

Regional Correlation

An important question with respect to addressing the mineral potential of the Tomiko supracrustal rock package is whether or not it developed *in situ*, or if it is correlative with other neighbouring metasedimentary sequences present in the Canadian Shield. Prior to discussing the *in situ* possibility, potential correlation with rocks of the Huronian Supergroup, the Frontenac terrane, the Baraboo interval, and the Mazatzal Orogen terrane are discussed below.

ARE THE TOMIKO SUPRACRUSTAL ROCKS CORRELATIVE WITH THE PALEOPROTEROZOIC COBALT GROUP OF THE HURONIAN SUPERGROUP?

The proximity (~20 km) of the supracrustal rocks of Tomiko terrane to exposed rocks of the Cobalt Group located immediately adjacent to the Grenville Front, as well as broad similarities in rock types, makes correlation with the Huronian Supergroup compelling. In such a correlation, the quartzose feldspathic gneisses would correspond to the Lorrain Formation; the metasiltstones, metapelites and some of the calc-silicate lenses would correspond to the Gordon Lake Formation; and the cleaner quartz arenites would represent the Bar River Formation. The iron formation present in Parkman Township might correspond to the middle member of the Gordon Lake Formation, which has a regional aeromagnetic expression (Card 1976). The main argument against this correlation is that it does not fit with the available isotopic data. Neodymium-samarium model ages for the supracrustal rocks (Holmden and Dickin 1995) are all less than 2340 Ma, typically averaging 2000 Ma, whereas one would expect Huronian Supergroup rocks to yield Archean Nd/Sm model ages. There is little difference in Nd/Sm model ages for quartzose gneisses on either side of the migmatite front north and south of Highway 63, making it unlikely that metamorphism has greatly affected the Nd/Sm results. In addition, the U/Pb zircon data of Krogh (1989) does not indicate the presence of Archean detrital grains, which one would expect in rocks of the Huronian Supergroup. Whole-rock geochemistry collected from the supracrustal rocks as part of this study, as well as additional sampling of the quartz arenites for U/Pb geochronology, should aid in determining if correlation with the Huronian Supergroup is realistic or not. In this respect, it may be worth noting that Easton (2002a) found that quartzose gneiss and metaconglomerate located in Flett Township, immediately north of the current study area, could not be correlated with the Huronian Supergroup on geochemical criteria. It is possible that metasedimentary gneisses in Flett Township are an outlier of the Tomiko supracrustal rocks.

ARE THE TOMIKO SUPRACRUSTAL ROCKS CORRELATIVE WITH MESOPROTEROZOIC METASEDIMENTARY ROCKS OF THE FRONTENAC TERRANE, CENTRAL METASEDIMENTARY BELT?

It has been suggested that rocks of the Parry Sound terrane represent tectonically transported rocks derived from the Central Metasedimentary Belt. Thus, it is necessary to consider that the Tomiko supracrustal rocks might represent a tectonically transported sliver of Frontenac terrane rocks, which is the only sequence in the Central Metasedimentary Belt containing extensive amounts of quartz arenite (Carr et al. 2000). This correlation is considered unlikely, for the following reasons:

- the Tomiko metasedimentary gneiss package is cut by the Mulock granite, suggesting that the package existed prior to about 1250 Ma, some 90 million years before Frontenac terrane started interacting with Laurentia (Carr et al. 2000). In addition, plutonic rocks that are about 1250 Ma in age are not characteristic of Frontenac terrane.
- Nd/Sm model ages for the Tomiko supracrustal rock package are 400 to 500 million years older than ages from metasedimentary gneisses from the Frontenac terrane
- none of the plutons in Tomiko terrane are characteristic of the Frontenac suite plutons of Frontenac terrane
- the presence of possible metavolcanic rocks, and abundant amphibolite associated with the quartz arenites of Tomiko terrane is uncharacteristic of Frontenac terrane

ARE THE TOMIKO SUPRACRUSTAL ROCKS CORRELATIVE WITH PALEOPROTEROZOIC QUARTZ ARENITES OF THE BARABOO INTERVAL?

The Baraboo and 6 other correlative red quartz arenites in the southern Lake Superior region were deposited between 1710 and 1630 Ma. Some of the quartz arenite sequences were affected by regional deformation and metamorphism at about 1630 Ma, as well as by a potassium metasomatic event at 1465 Ma (Medaris, Jr. et al. 2003). Some of the Baraboo quartz arenites were deposited on intermediate to felsic volcanic rocks and related high-level plutons that were emplaced at about 1765 Ma. Some of the quartz arenites are overlain by banded iron formation and black shale. The Baraboo and related quartz arenites may also be correlative with quartz arenites in the Athabasca and Thelon basins (Medaris, Jr. et al. 2003), indicating widespread sedimentation across much of North America in the late Paleoproterozoic. Key features of the Baraboo and related quartz arenites, as well as the Athabasca basin quartz arenites, include the local presence of well-developed paleosols, a high-degree of supermaturity of the quartz arenites, and chemical index of alteration (CIA) values of 95 to 99. These 3 features have been interpreted to indicate that profound chemical weathering occurred across much of North America between 1750 and 1630 Ma (e.g., Medaris, Jr. et al. 2003). The depositional environment has been interpreted to be in a fluviatile to shallow marine setting, possibly in a passive margin setting (Medaris, Jr. et al. 2003 and references therein).

Correlation of the Tomiko quartz arenites and muscovite-rich rocks with the Baraboo and related quartz arenites is compelling. The Tomiko quartz arenites appear to be mature to supermature in character, and are associated with intermediate to felsic orthogneisses (metamorphosed volcanic and plutonic rocks?) and minor amounts of iron formation. One can argue that the kyanite-bearing and muscovite-rich gneisses in Tomiko terrane represent a combination of metamorphosed paleosols and potassium metasomatized quartz-rich sedimentary rocks, respectively. Indeed, Watts, Griffis and McOuat and Ontario Geological Survey (2002) suggested independently that metasomatism was probably instrumental in creating some of the more muscovite-rich rocks in the terrane. The U/Pb zircon age of 1687±20 Ma (Krogh 1989), regardless of whether it is from an epiclastic or volcaniclastic rock, is consistent with this correlation. Holmden and Dickin (1995) also suggested correlation of the Tomiko supracrustal rocks with the Baraboo quartz arenites, but on the basis of isotopic and tectonic arguments.

ARE THE TOMIKO SUPRACRUSTAL ROCKS CORRELATIVE WITH PALEOPROTEROZOIC ROCKS OF THE MAZATZAL OROGEN?

Rocks of the Mazatzal Orogen crop out in Arizona and New Mexico, where they constitute the Tonto Basin Supergroup and the Hondo Group, respectively. Both the Tonto Basin Supergroup and the Hondo Group consist mainly of quartz arenite with minor shale, siltstone and calc-silicate rocks, associated with felsic metavolcanic rocks (Robertson et al. 1993). Rocks of the Tonto Basin Supergroup were deposited between 1720 and 1700 Ma and rocks of the Hondo Group were deposited between 1700 and 1644 Ma (Robertson et al. 1993). Quartz arenites from the Hondo Group contain detrital zircons ranging in age from 1850 to 1700 Ma. The metasedimentary and metavolcanic rocks are thought to have been deposited outboard of the slightly older (1790 to 1710 Ma) Yavapai Orogen. It is worth noting that the combination of rapid sedimentation of shelf-type siliciclastic rocks in conjunction with felsic volcanism, as seen in the Mazatzal Orogen, has no direct analogue in the Phanerozoic.

The Hondo Group overlies a sequence of older greenstones, and consists of a thin basal unit of quartz pebble conglomerate, over 1 km of quartz arenite that is capped by a sequence of muscovite schist and arenite, metarhyolite, phyllite and calc-silicate rocks (Robertson et al. 1993). A manganese-rich horizon, thought to be a possible paleosol, perhaps lateritic, occurs at the top of the greenstone sequence. Gresens (1971) suggested that some of the muscovite schists in the Hondo Group represented hydrothermally altered felsic volcanic rocks. The Tonto Basin Supergroup stratigraphy in Arizona is similar to that of the Hondo Group, but contains more felsic volcanic units, as well as some basalt horizons (Robertson et al. 1993). The Mazatzal supracrustal rocks are intruded by plutonic rocks of 1680 to 1650 Ma, similar in age to rocks of the Labrador batholith in the eastern Grenville Province in Labrador. The Mazatzal Orogen is also cut by Geon 14 plutons. The rock types, stratigraphy, thickness, alteration history and age of the Tonto Basin Supergroup and the Hondo Group are similar to that observed in the Tomiko supracrustal rocks, and provide a more compelling correlation than with the Baraboo quartz arenite, even though the Mazatzal rocks in New Mexico are now some 3500 km distant.

If correlation with the Mazatzal Orogen is valid, then it has the following implications.

1. Since the Tomiko supracrustal rocks are now in contact with likely Archean gneisses, rather than Paleoproterozoic metavolcanic rocks, it is likely that the Tomiko supracrustal rocks were thrust northward onto Laurentia, and that the heterogeneous gneiss unit represents structural, not depositional, basement to the supracrustal rocks.
2. The iron formation unit in northern Tomiko terrane may be equivalent to the manganese-rich unit at the base of the Tonto Basin Supergroup and the Hondo Group, and may have served as the décollement surface along which northward-directed thrusting occurred.

3. The supracrustal rocks are likely dominated by Paleoproterozoic detritus that has no direct link to Laurentia. Deposition of the Tomiko supracrustal rocks likely occurred between 1700 and 1650 Ma.

4. Similar styles of mineralization and alteration may be present in the Tomiko supracrustal rocks and the Mazatzal supracrustal rocks. The implications of this are explored further in "Mineral Potential".

In summary, it is conceivable that the Tomiko supracrustal rocks represent a sliver of the Mazatzal Orogen, which, at one time, must have stretched from Arizona to Labrador.

AN *IN SITU* ORIGIN FOR THE TOMIKO SUPRACRUSTAL ROCKS?

A final possibility is simply that the Tomiko supracrustal rocks represent a unique package of rocks deposited in what is now the North Bay area during the Paleoproterozoic, and that it is not correlative with any other orogenic belt or sedimentary basin in the Canadian Shield. As such, the terrane would possess a unique environment with respect to mineralization, making it difficult to identify potential exploration commodities or targets.

MINERAL POTENTIAL

Regional Metasomatism and its Effect on Rock Types, Stratigraphy and Mineral Potential

Previous workers (Hewitt 1952; Pearson 1959; Moore 1976; Vos, Smith and Stevenato 1981) have considered the biotite-garnet-kyanite gneisses in the Timber Lake area of eastern Tomiko terrane to be formed by metamorphism of pelitic rocks. Metapelitic rocks, however, are relatively uncommon in northeast Tomiko terrane, thus, their abundance and concentration in the Timber Lake area is difficult to explain stratigraphically. The similarity of the Tomiko supracrustal rock package to rocks in northern New Mexico described by Gresens (1971), however, suggests that consideration be given to the involvement of a hydrothermal or metasomatic process for the formation of the biotite-garnet-kyanite gneisses, most likely during M_2. Given the clear field evidence for the formation of kyanite during M_3 by replacement of granitic leucosome, possibly by hot, acidic fluids, a hydrothermal origin for biotite-garnet-kyanite gneisses in the Timber Lake area is less preposterous than it might otherwise seem.

Within the Hondo Group in New Mexico, Gresens (1971) described the development of muscovite-rich zones both in feldspathic metasedimentary rocks and metarhyolite related to fluids channelled along shear zones, as well as the local development of pegmatite pods where fluid flow was more intense. Several aspects of Tomiko terrane geology fit with Gresens (1971) observations, notably the development of both muscovite-rich zones and coarse granitic leucosomes within the feldspathic gneisses, which are derived from rocks of similar bulk composition to those studied by Gresens (1971). In addition, in some parts of the study area, thin-bedded quartz arenite can be observed grading into quartz-muscovite rocks, and then into more muscovite-rich and feldspar-rich gneiss. One explanation for this gradation is that it is related to increasing metasomatism of an original sequence of thin- to medium-bedded quartz arenite. Preliminary geochemical data suggests slight enrichment in the quartz-muscovite rocks of Be, Nb, W, Y and Zr, in addition to Ba, Pb, Sr, Rb and Th, relative to the contents of these elements present in quartz arenite, metapelitic and calc-silicate units in the terrane. The enrichment in these elements are most easily explained by a metasomatic or hydrothermal process. Although the enrichments detected so far are minor, the fact that the several elements appear to be coupled with one another, and were observed in samples collected for rock unit characterization rather than assay, is significant.

Furthermore, the development of other unusual rock types in the Timber Lake area, for example the pyrrhotite gneiss unit, the development of sulphide-rich zones within the biotite-garnet-kyanite gneiss, the formation of kyanite-rich (>60% kyanite) lenses and the almost complete replacement of biotite-garnet-kyanite gneiss by graphite along the biotite-garnet-kyanite gneiss contact, can all be related to a hydrothermal replacement process. In thin section, garnet within the biotite-garnet-kyanite unit is not zoned and lacks inclusion trails or inclusions of prograde metamorphic minerals, such as staurolite, and there is no other evidence in thin section for an earlier metamorphic history in these rocks. This textural evidence suggests that the biotite-garnet-kyanite gneiss originated from a rock that formed after M_1. On the basis of the data collected so far, a hydrothermal model best explains these observations, although it is quite possible that hydrothermal alteration may have been concentrated within a zone that had a metapelitic precursor. If a hydrothermal or metasomatic origin is correct, than it is likely that the distribution of the biotite-garnet-kyanite gneiss units and the pyrrhotite gneiss unit is not stratigraphically controlled, but may instead reflect the location of old shear zones or channelways.

Iron Formation Unit

Metapelitic gneiss that occurs structurally below the iron formation unit near Otter Lake contains thin (<10 cm) tourmaline + garnet-bearing layers; with 15 to 20% tourmaline, these rocks border on being true tourmalinites. Adjacent layers (beds?) contain no tourmaline or garnet. The garnets show rotated inclusion trails, indicating that they grew during regional metamorphism and deformation (M_1?). The pleochoric green tourmaline grains are euhedral, showing no relict cores, suggesting that they grew during metamorphism (M_1?), probably at the same time as the garnet, rather than being detrital grains. Boron-rich rocks have not been previously reported in association with the iron formation, or from elsewhere in Tomiko terrane.

Thin section examination of the amphibole gneiss that forms the bulk of the iron formation unit reveals that it consists of thin layers composed of large grains of amphibole, as well as some orthopyroxene and quartz layers. Fine opaque dust disseminated throughout the amphibole and pyroxene grains hinders precise mineral identification of the mafic minerals. Some layers contain relict garnet grains, possibly spessartine, armoured within large amphibole grains. None of the primary minerals are fresh, and it is likely that much of the magnetic character of these rocks is probably due to exsolution of iron oxides. It is unclear if this exsolution is due to regional metamorphism (M_1 or M_2?); is a retrograde effect; or if it represents a hydrothermal event that occurred after M_1 metamorphism. Despite the abundance of silicate phases in the rock, the amphibole gneiss has a high density. This dense character may be related to non-magnetic oxide minerals, most likely pyrolusite (MnO_2) or manganite ($MnO \cdot OH$). Samples of the magnetite-rich parts of the iron formation assayed in the 1950s by Iron City Mines Ltd. (1973) contain between 1.19 to 6.20 weight % Mn and, in some cases, Mn constitutes up to 30% of the oxide component of the rock. The highest total iron content reported by Iron City Mines Ltd. (1973) was 33.2 weight %. Seven assay samples collected from the amphibole-rich phase of the iron formation near Otter Lake all contain low contents of siderophile elements (<2 ppm Cu, <45 ppm Co, <45 ppm Ni; <3 ppm Sc, <22 ppm V), confirming that the amphibole-rich phase is not derived from a metamorphosed ultramafic intrusion.

The presence of boron- and manganese-rich rocks associated with the iron formation unit has not been previously recognized, and may indicate that the unit results from hydrothermal alteration, rather than from direct precipitation of iron in a marine environment. This unit deserves further exploration for other elements, such as gold, manganese, tungsten and zinc.

Building Stone

Between 1993 and 1995, R. Komarechka examined the monzonite body east of Eldee for its building stone potential. The polished rock has a mahogany colour, with some schiller. Unfortunately, the body is of limited areal extent, with the least deformed and most easily quarried exposures located beneath a communication tower located atop the hill formed by the intrusion.

Potassium feldspar megacrystic to augen granite of the Malone lobe of the Mulock granite might make an attractive pink stone. Areas of exposed rock exhibiting moderate relief and containing widely spaced joints are easily accessed along the logging road that extends north of Malone Lake.

Garnet

The best prospects within the region are associated with mafic gneisses (pseudoeclogite) present in the Mattawan domain in Mattawan Township, as these contain garnet of uniform size and quality, with minimal inclusions. Garnet is locally abundant anywhere in Tomiko terrane where either M_2 or M_3 are the dominant metamorphic events. Garnet is most common in metapelitic or interlayered amphibolite bands in the metasedimentary sequence. In Tomiko terrane, garnet production is more likely to occur as a by-product of either kyanite or mica extraction.

Graphite

Pearson (1959) described the presence of graphite at the contact of garnet-kyanite gneiss and surrounding mafic and metasedimentary gneisses in the Crocan Lake area. Massive graphite is locally exposed at this contact at the Kyanite Corporation of America mill site, and consists of massive, coarse flake graphite in a lens up to 1.5 m wide and at least 5 m long. Pearson (1959) suggested that the graphite replaced the pre-existing rocks. Evidence for replacement is observed locally, as parts of the graphite occurrence contains clots of bright red weathering hematite and goethite that is likely derived from alteration of primary garnet as well as remnant kyanite grains. Although the volume of graphite may not be sufficient to sustain a mining operation, given the coarseness of the flake and the massive character of the graphite, it could be an important by-product of the kyanite mining operation.

Kyanite

The economic potential of kyanite occurrences in the Timber and Crocan lakes area has been studied since 1951 (Hewitt 1952; Pearson 1959; Moore 1976; Vos, Smith and Stevenato 1981; Blais and Associates Ltd. 1998), culminating in extraction of a test sample from the Kyanite Corporation of America property in 1998 (Blais and Associates Ltd. 1998). The property is currently idle, but remains the best target for kyanite within Tomiko terrane. Northeast of Highway 63, kyanite, although present, is not abundant and has been partly replaced by muscovite. South of Highway 533, as noted in "Metamorphism", blue kyanite occurs in metapelitic gneiss (M_2) and was variably replaced by green kyanite during M_3. As a consequence, kyanite occurrences south of Highway 533 (*see* Figure 16.2) contain at least 2 varieties of kyanite, of different colour, habit, inclusions, and associated host minerals; all factors that will complicate mineral extraction and processing and, thus, the economic viability of any kyanite prospect. If exploring for kyanite south of Highway 533, the best targets are located on the hydroelectric line near Cahill Lake, where almost complete replacement of blue kyanite by green kyanite has occurred.

Muscovite

Watts, Griffis and McOuat and Ontario Geological Survey (2002) evaluated muscovite occurrences in Tomiko terrane, specifically the Reynolds Lake properties of [illegible]ren's Bay Mica (Wayne Borer) and Mote (Garmak Investments), and the Porcupine Lake, Threetrail Lake and Thorne Brilliant Stone quarries. All of these sites are located northeast of Highway 63 and are situated in the less metamorphosed part of the terrane, which remains the best area for muscovite exploration. Beneficiation tests were conducted on samples from the 2 Reynolds Lake properties. These samples had fewer inclusions and were coarser grained than samples from other parts of the Grenville Province in Ontario, but had higher iron content, which may preclude the use of this muscovite in the plastics and paint industry (Watts, Griffis and McOuat and Ontario Geological Survey 2002). Muscovite from the Kyanite Corporation of America occurrence at Crocan Lake was also examined, and although it possesses lower iron content, was less abundant (<20%) than at the other Tomiko occurrences (30 to 80%) (Watts, Griffis and McOuat and Ontario Geological Survey 2002).

Coarse muscovite was previously extracted from granite pegmatite veins associated with amphibolite and garnet amphibolite enclaves within the Bonfield pluton in the Bonfield domain in south Olrig and southwest Mattawan townships. Most of the production came from the Purdy Mine (Harding 1946).

Silica

Exploration for quartz arenites for silica extraction should focus on the area northeast of Highway 63, which is where most past-producers are located. Quartz arenites in this area generally contain few accessory minerals, such as feldspar, and are weakly to non-migmatitic. The area east and south of Tower Lake in Garrow Township has excellent potential, but has not been explored recently. South and east of Highway 63, the quartz arenite units are migmatitic and, thus, contain abundant feldspar and mica, making silica extraction more complicated.

Vermiculite

Discovered in 1957, during the construction of what is now Highway 533, several vermiculite occurrences northwest of Timber Lake have received extensive exploration interest (e.g., Millar vermiculite in Vos, Smith and Stevenato 1981). Currently, Enviro Industrial Technologies (Canada) Inc. is building a mill on the west end of the former Millar property for the purposes of producing vermiculite concentrate. The deposits are associated with weathered zones developed in amphibolite and calc-silicate gneiss that are interlayered with felsite of the metasedimentary sequence. All the occurrences are located within 1 km of the eastern margin of the Jocko pluton. The Jocko pluton and related plutonic bodies are highly friable, locally developing thick saprolite mantles. Since these zones of intense weathering are largely restricted to this one rock unit, the close proximity of the vermiculite occurrences to the pluton may be related, possibly to fluid movement during pluton emplacement. If so, exploration for vermiculite should focus on the margins of the Jocko pluton and compositionally similar plutons in the area.

Broken Hill-Type Mineralization

There are some similarities between the Tomiko supracrustal rocks and the Willyama Supergroup in the Broken Hill area. These include the presence of a psammitic sequence with amphibolite layers (Cahill Lake sequence of Moore (1976) = lower Freyers metasediments) overlain by a sequence of calc-silicate gneiss, pyrrhotite gneiss, pelitic gneiss and amphibolite (Crocan Lake sequence of Moore (1976) = upper

Freyers metasediments or Sundown Group). Migmatitic rocks occur in the south part of Tomiko terrane. Rocks with unusual mineralogy (e.g., rich in boron or manganese) are present locally, at least in north Tomiko terrane. Notable differences are the apparent abundance of fairly mature quartz arenite within the succession (unlike the turbidite-dominated Willyama Supergroup), and the dominance of kyanite rather than sillimanite. Overall, the differences probably outweigh the similarities, and would lead to the conclusion that the Tomiko terrane may not be a favourable host for Broken Hill-type mineralization.

Furthermore, if it turned out that the correlation with the Baraboo and related quartz arenites was correct, then the inferred depositional setting of a fluviatile to shallow marine setting on a passive margin would be inconsistent with the extensional setting envisioned by many workers for the Broken Hill district (Stevens, Burton and Leyh 1998; Stevens, Gibson and Page 2000). Massive sulphide mineralization has not been reported in association with the Baraboo and related quartz arenite units.

Alternatively, it is possible that the critical elements responsible for mineralization are not controlled by rock type or stratigraphy. Rather, the critical elements may depend on the presence of a rapidly deposited, Geon 16 metasedimentary sequence associated with felsic or bimodal volcanism, which contains rocks of unusual composition (e.g., rich in boron, manganese, tungsten) and which has evidence for significant fluid flow. If this is the case, then the Tomiko terrane may very well be an excellent host for Broken Hill-type or other types of sulphide mineralization. It is also possible that this may be a unique Paleoproterozoic environment that has no direct analogue in the Phanerozoic.

In terms of fluid flow regimes, this study has identified the presence of at least 3 major fluid flow events: a pre-M_1 event in northern Tomiko terrane that formed the tourmalinites and manganese- and iron-rich rocks; a pre-M_2 event in the Timber Lake area that may have formed the biotite-garnet-kyanite gneisses; and a M_3 event that resulted in the replacement of biotite-garnet-kyanite rocks in the Timber Lake area by graphite, and the development of quartz-kyanite segregations replacing M_2 leucosome between Timber Lake and Cahill Lake. Certainly, the widespread evidence in Tomiko terrane for extensive fluid flow at several times in its history is a favourable indicator for mineralization.

SUMMARY

In conclusion, the answers to the main questions (*see* "Introduction") addressed by this study are:

- Tomiko terrane may indeed be a favourable host for metallic mineralization. This is based on the evidence for several fluid-flow events in the terrane, the presence of metavolcanic rocks in the terrane, and the local evidence of rocks of unusual composition (e.g., rich in boron or manganese). It is more difficult, however, to reach a conclusion with respect to the presence of Broken Hill-type zinc-lead mineralization. Based on the available data, such mineralization cannot be ruled out entirely, but its potential is probably best described as low.
- Industrial mineral potential in the terrane is good, and includes graphite, garnet, kyanite and silica.
- Additional detailed field work could be undertaken in Parkman Township to better understand the distribution and stratigraphy of the iron formation unit and related tourmaline-bearing rocks. Detailed mapping and structural analysis in the Timber Lake area might help to determine if the biotite-garnet-kyanite gneisses are stratabound or if they are discordant to stratigraphy.

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17. Project Unit 00-101. Summary of Geophysical Projects and Activities

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[1]Precambrian Geoscience Section, Ontario Geological Survey

INTRODUCTION

Geophysical projects and activities have been directed towards integrating geology with geophysics in order to enhance the understanding of Ontario geology; the publication of high-resolution airborne geophysical data to assist mineral exploration efforts within the province; and client support. Geophysical projects and activities for 2003 covered the following areas:

1. support for the bedrock mapping program
2. geophysical data releases
3. regional geoscience initiatives
4. training and education
5. other activities

As this year has seen the release of the remaining Operation Treasure Hunt (OTH) data sets, a section summarizing the geophysical projects, that were carried out as part of the OTH program, is included here.

SUPPORT FOR THE BEDROCK MAPPING PROGRAM

Geophysical support for bedrock mapping projects continues for the Precambrian Geoscience Section of the Ontario Geological Survey (OGS) as part of a strategy to enhance the value of products through field mapping, interpretation and modelling. Mapping projects now routinely utilize magnetic, EM, gravity and resistivity and/or conductivity data and corresponding derivatives. Assistance is provided to field geologists through preparation of digital images and hard-copy maps using a variety of display techniques. Integrating geophysics into mapping projects has been facilitated by the availability of high-quality airborne survey data that have been acquired in recent years, particularly through Operation Treasure Hunt. Geographic information system (GIS) software is increasingly being used to aid in the integration and interpretation process.

Many geologists are now routinely using hand-held magnetic susceptibility meters during mapping. Data collected are used by the geologists to assist in assessing characteristics of various rock units for interpretation purposes. The data, which will result in more effective interpretation and modelling of the airborne magnetic results through the use of comparative ground-controlled measurements, will be incorporated into a master database for Ontario.

Summary of Field Work and Other Activities 2003,
Ontario Geological Survey, Open File Report 6120, p.17-1 to 17-5.

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The following projects are currently utilizing geophysical data and derived products:

- central Wabigoon area (project unit 95-014)
- Abitibi greenstone belt compilation (project unit 95-024)
- Shining Tree south area (project unit 96-003)
- Hudson Bay–James Bay lowlands Archean substrate (project units 98-006 and 98-007)
- Matachewan to Kirkland Lake area (project unit 00-010)
- Shaw–Eldorado–Adams townships (project unit 00-011)
- Henry–Loughrin townships (project unit 02-008)
- Kakagi Lake area (project unit 02-011) (Sedimentary Geoscience Section)
- Nipigon south-central area (project unit 03-001)
- Menzies Township (project unit 03-002)
- eastern Tomiko terrane (project unit 03-009)

DATA RELEASES

Airborne geophysical survey data were released for 7 areas during 2003. The Fort Hope survey data were newly acquired, and the remaining data were purchased from or donated (in the case of the Kenogami River area) by various mining companies. Total line-kilometres[1] for the surveys was 328 480 km. Table 17.1 summarizes the information for these data sets.

Table 17.1. Releases of airborne geophysical survey data in 2003.

Survey Name	**Publication No.**	**Release Date**	**Flown For**	**Flown By**	**Survey Type**	**Line-Kilometres**
Fort Hope Area (TDEM)	GDS 1108	July	OGS	Fugro	mag; TDEM (Geotem)	38 597
Fort Hope Area (mag)	GDS 1109	August	OGS	Fugro–Sial, Terraquest	mag	105 111
Fort Hope Area (spec)	GDS 1110	TBA	OGS	Fugro–Sial, Terraquest	spec	69 596
Attawapiskat	GDS 1211	November	Spider Resources	High Sense	mag	118 057
Albany–Atikameg–Attawapiskat	GDS 1212	November	Diabras Exploration	Sial, Terraquest	mag	17 120
Kenabeek–Latchford–Redwater	GDS 1224	April	DeBeers	Aerodat, Kenting	mag	7472
Nagagami–Squirrel–Wakashi Rivers	GDS 1225	November	North Atlantic Nickel	Terraquest	mag	4521
Nipigon Bay	GDS 1226	April	Falconbridge	Geoterrex	mag; TDEM (Geotem)	1252
Kenogami River	GDS 1227	December	Aur Resources	Questor	mag	36 350

Abbreviations: mag = total field magnetics; TDEM = time domain electromagnetics; spec = gamma ray spectrometer; TBA = to be announced

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[1] The Fort Hope spectrometer survey was not added to the total as the spectrometer data were collected as part of the magnetic survey.

Thirty-four data sets, representing 33 airborne surveys, were re-released after conversion from the existing Centurion format to ASCII and Geosoft® formats. The publication numbers are Geophysical Data Sets (GDS) 1001 to 1034, inclusive. This year, the results of 12 airborne surveys, were re-released after levelling (micro-levelling and "GSC-levelling") to the Ontario Single Master Aeromagnetic Grid datum, published as GDS 1039, 1100 to 1106, 1201, 1202, 1204 and 1223. Any OTH surveys adjacent to existing surveys have been merged to form new supergrids scheduled to be released in December 2003.

REGIONAL GEOSCIENCE INITIATIVES

Support has been provided to the Discover Abitibi Initiative and Lake Nipigon Region Geoscience Initiative (LNRGI) government-industry collaborative projects. Assistance with the publication of digital data sets, from recently flown airborne geophysical surveys, and the integration of geophysical data into the Metallogenic Architecture Project, is being provided to the Discover Abitibi Initiative.

Participation in the LNRGI included the specification of a 49 000 km magnetic and gamma-ray spectrometer survey covering the western and southern flanks of Lake Nipigon and a 3600-station ground gravity survey. The airborne survey was completed in August and the gravity survey is expected to be completed in November, 2003. Both surveys will be used to improve the understanding of the structure of the Nipigon embayment and will assist the geological mapping projects as well as the exploration community. The geophysical data are being augmented by magnetic susceptibility and density data collected as part of bedrock mapping.

TRAINING AND EDUCATION

Basic geophysical training for use by prospectors was delivered to the Eabametoong and Marten Falls First Nations communities in advance of the Fort Hope airborne geophysical survey releases. The purpose of training was to provide community members with an understanding of the types of information collected by the airborne geophysical surveys, the maps that are generated from the surveys and how they can be used for prospecting.

Presentations, on the application of regional-scale geophysics for gold exploration, were given at gold exploration workshops at the Northwest and Northeast Ontario Mines and Minerals symposia.

OTHER ACTIVITIES

There is a continued focus on client support, consisting primarily of responding to enquiries from the public and assistance to other groups within the OGS and external groups. The Geophysical Atlas, available on the web (http://www.mndm.gov.on.ca/MNDM/MINES/OGS/gpxatlas/index_e.asp), is updated periodically and is a good source of information on the availability of geophysical data from the OGS. Other activities have included providing assistance with display development to the newly opened Dynamic Earth geoscience centre in Sudbury; and the acquisition of archived airborne data for eventual public release.

SUMMARY OF GEOPHYSICAL PROJECTS IN OPERATION TREASURE HUNT

Over the course of the three-year initiative, the OGS flew 9 new airborne geophysical surveys and purchased 27 proprietary geophysical data sets—encompassing over 574 000 line-kilometres of survey over a total area of about 134 000 km^2. These surveys have generated 596 separate map tiles and approximately 100 gigabytes of compressed geophysical data (survey details in Table 17.2; *see* Figure 17.1 for survey locations).

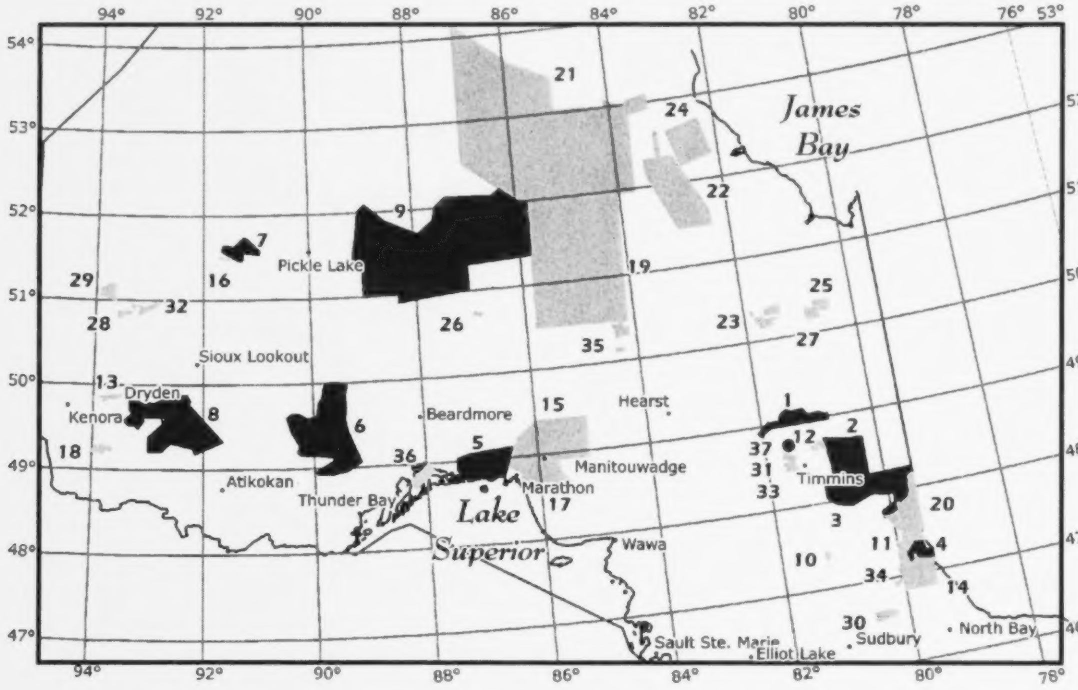
Table 17.2. Summary of geophysical data acquired under Operation Treasure Hunt

Map Key		Data Set Number[a]	Type of Survey[b]	Year Survey Flown	Survey Area (km^2)	Line-km	Line Spacing	Publication Date
OGS Surveys								
1	Cochrane	1100rev	TDEM-MAG	1999	1219	7082	200	20-Jul-2000
2	Matheson	1101rev	TDEM-MAG	2000	1758	10 902	200	13-Sep-2000
3	Kirkland Lake	1102rev	TDEM-MAG	1999–2000	4943	28 263	200	17-Aug-2000
4	Temagami	1103rev	TDEM-MAG	2000	630	3657	200	27-Jul-2000
5	Schreiber	1104rev	FDEM-MAG	1999–2000	2658	13 936	200	03-Aug-2000
6	Garden–Obonga	1105rev	FDEM-MAG	1999	6748	38 223	200	31-Aug-2000
7	Vickers	1106rev	FDEM-MAG	2000	856	5107	200	20-Jul-2000
8	Stormy Lake	1107rev	TDEM-MAG	2000–2001	5866	33 874	200	11-Dec-2001
9	Fort Hope (Block 4)	1108	TDEM-MAG	2001–2002	6546	38 597	200	19-Feb-2003
9	Fort Hope (Blocks 1,2,3)	1109	MAG	2001–2002	22 924	105 111	250	05-Feb-2003
9	Fort Hope (Blocks 1,2)	1110	SPEC	2001–2002	15 199	69 596	50	to be released
	Totals				69 346	354 348		
Purchased Surveys								
10	Amyot–Browning	1200rev1	TDEM-MAG	1994	99	789	150	01-Aug-2001
11	Cobalt	1201rev1	TDEM-MAG	1993	131	453	300	01-Aug-2001
12	Gowan–Evelyn	1202rev1	FDEM-MAG	1991	191	1946	100	01-Aug-2001
13	Docker	1203rev1	FDEM-MAG	1993	198	940	200	01-Aug-2001
14	Temagami South	1204rev1	TDEM-MAG	1992–1993	796	3961	200, 300	01-Aug-2001
15	Geco–Manitouwadge	1205rev	FDEM-MAG	1985–1989	5965	35 700	150, 200	01-Aug-2001
16	Gitche Lake	1206rev1	FDEM-MAG	1990	66	626	100	01-Aug-2001
17	Hemlo	1207rev	FDEM-MAG	1983	1619	15 770	100	01-Aug-2001
18	Kakagi Lake	1208rev1	TDEM-MAG	1997	283	1545	200	01-Aug-2001
19	Albany River–James Bay	1209rev	MAG	1993–1995	19 014	35 680	400	01-Aug-2001
20	Temiskaming	1210rev1	MAG	1992–1993	2030	14 747	125	01-Aug-2001
21	Attawapiskat	1211	MAG	1993–1996	35 709	118 057	200, 400	26-Nov-2003
22	Albany–Atikameg–Attawapiskat	1212	MAG	2000	5822	17 120	200, 400	27-Nov-2003
23	Coral Rapids	1213rev	MAG	1993	634	4475	150	11-Dec-2001
24	Kapiskau River East	1214rev	MAG	2000	2354	10 026	250	11-Dec-2001
25	Kesagami Lake	1215rev	MAG	1993	304	1607	200	11-Dec-2001
26	Melchett Lake	1216rev	TDEM-MAG	1991	88	366	250	11-Dec-2001
27	Natogami Lake	1217rev	FDEM-MAG	1996	301	1067	300	11-Dec-2001
28	Pakwash Lake	1218rev	TDEM-MAG	1992	125	642	250	11-Dec-2001
29	Red Lake-East Bay	1219	TDEM-MAG-SPEC	1998	377	4327	100	to be released
31	River Valley West	1220rev	FDEM-MAG	1995	315	1892	200	11-Mar-2002
31	Robb-Jamieson	1221rev	TDEM-MAG	1992	186	1973	100	11-Mar-2002
32	Troutlake River	1222rev	TDEM-MAG	1997	277	1465	200	11-Dec-2001
33	Turnbull–Godfrey	1223rev	TDEM-MAG	1998	197	1058	200	11-Mar-2002
34	Kenabeek–Latchford–Redwater	1224	MAG	1983	1801	7472	200, 250	16-Apr-2003
35	Nagagami–Squirrel–Wakashi Rivers	1225	MAG	2000	832	4521	200	26-Nov-2003
36	Nipigon Bay	1226	TDEM-MAG	1994	498	1252	350	9-Apr-2003
	Totals				80 212	289 477		
37	Reid–Mahaffy Test Site	MRD 55	TDEM-FDEM-MAG				200	6-Jul-2000
	Grand Totals				**149 574**	**645 066**		

[a] Data Set Numbers refers to Geophysical Data Sets (GDS), unless otherwise indicated; MRD is Miscellaneous Release—Data

[b] Types of Surveys: TDEM, time domain electromagnetic survey; FDEM, frequency domain electromagnetic survey; MAG, magnetic survey; SPEC, gamma-ray spectrometric survey.

The OGS awarded the new airborne surveys to 6[2] separate geophysical contractors. A total[3] of 285 000 line-kilometres of survey were completed covering an area of over 54 000 km^2. The OGS also sought out and purchased proprietary airborne geophysical data that complemented existing public domain data. Selection of airborne geophysical surveys were based on the survey i) date, ii) method, iii) location, iv) line spacing and v) data quality, as well as other criteria, such as the area's potential mineral significance, previous exploration activity and land availability. In all, 27 airborne geophysical surveys were purchased, totalling 288 477 line-kilometres and covering over 80 000 km^2.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James Bay
Lake Superior
Pickle Lake
Sioux Lookout
Kenora
Dryden
Atikokan
Thunder Bay
Beardmore
Marathon
Manitouwadge
Hearst
Timmins
Wawa
Sault Ste. Marie
Elliot Lake
Sudbury
North Bay
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Figure 17.1. Operation Treasure Hunt – location of all OGS surveys (black) and purchased surveys (grey); survey numbers tied to "Map Key" in Table 17.2.

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[2] The companies initially awarded the contracts were Geoterrex-Dighem, High-Sense, Spectrem, Fugro-Sial and Terraquest. Geoterrex-Dighem and High-Sense were subsequently acquired by Fugro Airborne Surveys during the course of the OTH initiative.

[3] Totals differ from those in Table 17.2 because Fort Hope blocks 1 and 2 are repeated for magnetic and spectrometer data.

Sedimentary Geoscience Section

18. Project Unit 02-016. Aggregate Resource Inventory Program

C.L. Baker[1]

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INTRODUCTION

Mineral aggregates, which include bedrock-derived crushed rock as well as naturally formed sand and gravel, constitute the major raw material in Ontario's road-building and construction industries. Very large amounts of these materials are used each year throughout the Province. For example, in 2000, the total tonnage of mineral aggregates extracted in Ontario was 170 million tonnes (Mt), greater than that of any other metallic or non-metallic commodity mined in the Province of Ontario (Ontario Aggregate Resources Corporation 2000).

Although mineral aggregate deposits are plentiful in Ontario, they are fixed-location, non-renewable resources that can be exploited only in those areas where they occur. Mineral aggregates are characterized by their high bulk and low unit value so that the economic value of a deposit is a function of its proximity to a market area as well as its quality and size.

Comprehensive planning and resource management strategies are required to make the best use of available resources, especially in those areas experiencing rapid development. In some cases, the best aggregate resources are found in or near areas of environmental sensitivity, resulting in the requirement to balance the need for different natural resources. Therefore, planning strategies must be based on a sound knowledge of the total mineral aggregate resource base at both local and regional levels. The purpose of the Aggregate Resources Inventory Program is to provide the basic geological information required to include potential mineral aggregate resource areas in planning and resources management strategies. The reports should form the basis for discussion on those areas best suited for possible extraction. The aim is to assist decision-makers in protecting the public interest by ensuring that adequate resources of mineral aggregate remain available for future use.

The staff of the Sedimentary Geoscience Section, Mines and Mineral Division, Ministry of Northern Development and Mines conduct the Aggregate Resources Inventory Program. The aggregate program was initiated in the late 1970s as a result of recommendations contained in "A Policy for Mineral Aggregate Resource Management in Ontario", the report of the Ontario Mineral Aggregate Working Party (1977).

To date, over 170 aggregate reports with accompanying maps have been produced. Most of these reports cover townships or counties within the southern part of the province due to the higher resource demands as well as population and land use pressures in those areas. A number of reports have also been generated for some of the urban areas and transportation corridors in northern Ontario as well as less populated regions where aggregate information was required for specific purposes.

Summary of Field Work and Other Activities 2003, Ontario Geological Survey, Open File Report 6120, p.18-1 to 18-3.

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The majority of Aggregate Resources Inventory Papers produced between 1979 and 1996 outlined the aggregate resources of a single township. There are several instances, however, where a number of townships were grouped together in a report, generally because they either represented a restricted geographic area or contained limited aggregate deposits. Aggregate reports published since 1996 cover an entire county or regional municipality.

Starting in 1996, updated or revised aggregate reports were produced for those areas in which the reports were up to 15 years in age and in which there had been significant urban growth or development. These reports, encompassing an entire county or regional municipality, involved the amalgamation of previously published aggregate reports for the area as well as the incorporation of new geological data and aggregate production information.

Aggregate Resource Inventory Papers are technical background documents, based for the most part on geological information and interpretation conducted by professional geologists. They are designed to be used as a component in the total planning and resource management process, in conjunction with other planning considerations, to ensure the best use of an area's resources. The reports include an assessment of sand and gravel resources as well as a discussion on the potential for bedrock-derived aggregate. The most recent geologic information available is used to prepare the reports. As new information becomes available, revisions may be necessary.

ASSESSMENT OF SAND AND GRAVEL RESOURCES

All sand and gravel resource areas in a report area are first delineated by geological boundaries and then classified into 3 levels of significance: primary, secondary and tertiary. Sand and gravel resource areas of primary significance are areas in which a major resource is known to exist and should be considered as part of the aggregate supply of the area. Deposits of secondary importance may contain significant amounts of sand and gravel. Although these deposits are not considered to be the "best" resources in the report area, they may contain large quantities of sand and gravel and are considered as part of the aggregate supply of the area. Tertiary deposits are not considered to be important resource areas because of their low available resources or because of possible difficulties in extraction. Such areas may be useful for local needs or extraction under a wayside permit, but are unlikely to support large-scale development.

It should be noted that the type and volume of aggregate resources in an area influence to which level of significance deposits are assigned. Where plentiful aggregate resources exist, primary areas normally consist of thick deposits containing a high percentage of gravel. In areas where aggregate deposits are scarce, sand-rich or thinner deposits may be ranked as primary or secondary, as they are the major aggregate source in that jurisdiction.

The process by which deposits are evaluated and selected involves the consideration of 2 sets of criteria. The main selection criteria are site specific, related to the characteristics of individual deposits. Factors including deposit size, aggregate quality, and deposit location and setting are considered in the selection of those deposits best suited for extractive development. A second set of criteria involves the assessment of local aggregate resources in relation to the quality, quantity and distribution of resources in the region in which the report area is located. The intent of such a process of evaluation is to provide decision-makers with a technically sound information base. This data, in combination with other information, will allow informed land use and planning decisions including the protection of sufficient resources to meet possible future demands.

ASSESSMENT OF BEDROCK RESOURCES

Criteria equivalent to those used for sand and gravel deposits are used to select bedrock areas most favourable for extractive development. The evaluation of bedrock resources is made primarily on the basis of performance and suitability data established by laboratory testing at the Ontario Ministry of Transportation. Deposit "size" is related directly to the areal extent of thin drift cover overlying favourable bedrock formations. Since vertical and lateral variations in bedrock units are much more gradual than in sand and gravel deposits, the quality and quantity of the resource are usually consistent over large areas.

Quality of the aggregate derived from specific bedrock units is established by the performance standards previously mentioned. Location and setting criteria and regional considerations are identical to those for sand and gravel deposits. Selection of Bedrock Resource Areas has been restricted to a single level of significance. Three factors support this approach. First, quality and quantity variations within a specific geological formation are gradual. Second, the areal extent of a given quarry operation is much smaller than that of a sand and gravel pit producing an equivalent tonnage of material, and third, since crushed bedrock has a higher unit value than sand and gravel, longer haul distances can be considered. These factors allow the identification of alternative sites having similar development potential.

Selected Bedrock Resource Areas are not permanent, single land use units. They represent areas in which a major bedrock resource is known to exist and may be reserved wholly or partially for extractive development and/or resource protection, within an Official Plan.

CURRENT PROGRAMS

Aggregate resource inventory studies from several areas are now nearing completion; these areas include Huron, Grey and Renfrew counties. Additionally, work is being conducted in the Regional Municipality of York.

One aspect of the aggregate mapping program that is being examined is the use of computer applications for determining regional drift thickness and, by extension, Selected Bedrock Resource Areas. The existence of digital water well data sets, digital elevation models (DEMs) and advanced computing software has enabled the construction of refined drift thickness maps. Before this digital mapping can be incorporated into the aggregate reports, suitable (i.e., standardized) methodologies and protocols have to be developed and tested. Work on this endeavour is proceeding so that it may be incorporated into the next generation of aggregate inventory reports.

REFERENCES

Ontario Aggregate Resources Corporation 2000. Mineral aggregates in Ontario: Statistical Update; the Ontario Aggregate Resources Corporation, 20p.

Ontario Mineral Aggregate Working Party 1997. A policy for mineral aggregate resource management in Ontario; Ministry of Natural Resources, 232p.

19. Project Unit 03-017. Regional Modern Alluvium Sampling Survey of the Kirkland Lake–Matachewan Region, Northeastern Ontario

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[1]Sedimentary Geoscience Section, Ontario Geological Survey

INTRODUCTION

In recent years, the discovery of kimberlites and other rocks (i.e., lamprophyres) thought to have potential to host diamonds in the New Liskeard–Cobalt–Kirkland Lake area of northeastern Ontario, has triggered an increase in diamond exploration across the region. The thickness of glacial sediments in this region ranges from nil to greater than 100 m. Kimberlite, being relatively soft, has been differentially eroded by preglacial weathering and glacial erosion such that it subcrops 3 to 35 m below the surrounding bedrock (McClenaghan et al. 1999a). Because of this deep erosion, all kimberlite pipes in the area are covered by glacial sediments and have no surface expression. Other rocks of interest for diamond potential in the region are similarly covered by varying thicknesses of glacial materials. Through indicator mineral and geophysical surveys, several kimberlite pipes and dikes have been discovered in the region within the last 15 years (McClenaghan et al. 1999b).

Indications are that exploration for kimberlite remains very active throughout northeastern Ontario. Over 29 000 new claim units have been recorded within the Temagami–Marten River survey area following the release of the Temagami–Marten River indicator mineral report in April 2001. Since the release of the Mattawa–Cobalt corridor indicator mineral report in June 2002, over 8900 new claim units have been recorded in that area alone. Over 4000 new claim units have been recorded in the New Liskeard–Elk Lake area since the summer of 2002 (V. Felix, OGS, personal communication, 2003).

BACKGROUND AND CURRENT STUDY

Kimberlite is a rock type commonly recognized as the primary host for diamond. The suite of kimberlite indicator minerals is known to include pyrope and eclogitic garnets, magnesium ilmenite, chromite, chrome diopside, forsteritic olivine and diamond. The presence of these indicator minerals in modern alluvium samples can be used to determine the prospect for and proximity of any diamond-bearing kimberlites in an area. As well, other heavy mineral assemblages including gold grains and metamorphic or magmatic massive sulphide indicator minerals (MMSIM®[1]) may be recovered from collected samples and utilized to assess mineral potential of a region.

To further evaluate the diamond and other mineral potential of the Mattawa to Timmins corridor of northeastern Ontario, the Ontario Geological Survey has completed a series of modern alluvium surveys in the region including 1) the Temagami–Marten River area (Allen 2001); 2) the Mattawa–Cobalt Corridor (Reid 2002a); and 3) the Cobalt–Elk Lake area (Reid 2002b). The current study, covering the

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[1] MMSIM is a registered trademark of Overburden Drilling Management Limited, Nepean, Ontario

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Kirkland Lake–Matachewan region is an extension of the survey completed in 2002 (Figure 19.1). The primary objective of the study is to extend the regional information base concerning the types and distribution of kimberlite indicator minerals (KIMs) found in modern alluvium northwestward to the Timmins area.

Previous till sampling surveys carried out within the north-central part of the current study area revealed a spatial pattern of kimberlite indicator mineral occurrences suggesting a local source for kimberlite indicator mineral grains (Baje and Crabtree 2001). Linear clusters of samples containing

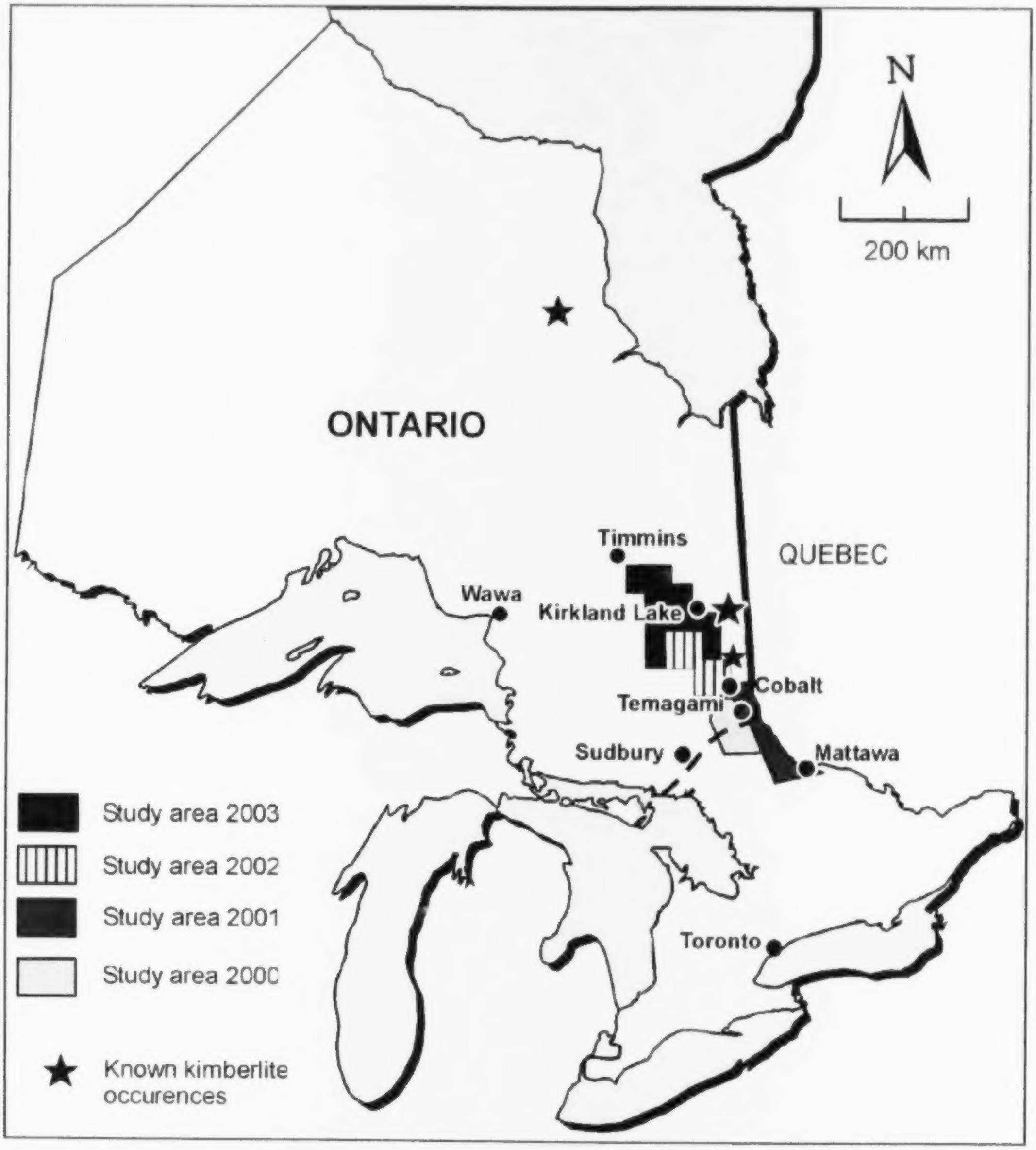
N
200 km
ONTARIO
QUEBEC
Timmins
Wawa
Kirkland Lake
Cobalt
Temagami
Sudbury
Mattawa
Toronto
Study area 2003
Study area 2002
Study area 2001
Study area 2000
Known kimberlite occurences

Figure 19.1. Location of the 2003 study area in relation to the 2000, 2001 and 2002 study areas. Locations of known kimberlites from Sage (1996). Dashed line approximates the Grenville Front.

indicator minerals were revealed by the till sampling survey and proposed to be associated with structural features present within the study area (Bajc and Crabtree 2001). Results from the current modern alluvium survey will be used to corroborate and build upon the indicator mineral data generated by previous work and in addition, add to the overall heavy mineral indicator database for the region.

The Kirkland Lake–Matachewan study area is represented on 12, 1:50 000 scale National Topographic System (NTS) map sheets. The north part of the study area is covered by the Watabeag River sheet (42 A/7), the east half of the Timmins sheet (42 A/6), the northeast corner of the Peterlong Lake sheet (42 A/3), the Radisson Lake sheet (42 A/2), the west half of the Kirkland Lake sheet (42 A/1) and the southwest corner of the Ramore sheet (42 A/8). The southwest part of the study area is covered by the Matachewan (41 P/15) and Gowganda (41 P/10) sheets. The southeast part of the study area is covered by the Charlton sheet (41 P/16), the west part of the Englehart sheet (31 M/3), the northeast corner of the Elk Lake sheet (41 P/9) and the northwest corner of the New Liskeard sheet (31 M/12).

A network of primary and secondary roads and all-terrain vehicle (ATV) trails provided reasonable access to the study area. The presence of numerous lakes and rivers provided boat access to otherwise remote locations. The larger lakes allowed for floatplane access and very remote sites were accessed by helicopter.

PHYSIOGRAPHY

The study area is situated in a physiographic division of the Canadian Shield known as the Abitibi Uplands (Bostock 1976). These uplands are underlain by crystalline Archean rocks and characterized by broad rolling surfaces that rise gently from Hudson Bay Lowland in the north, reaching about 500 m asl near their southwest and southern extent. Most of the uplands lie between 300 and 400 m asl in elevation. Extensive areas of the northern Abitibi Uplands are mantled by glacial lake deposits. These uplands form a rocky landscape, scattered with lakes and large areas underlain by glacial deposits consisting of glaciolacustrine clays and beach deposits of former proglacial lakes. Other glacial deposits and landforms found in this area include outwash channels, till and moraines (Thurston 1991).

The region surrounding Timmins is one of low relief and a thick mantle of glaciolacustrine clay and silt covers much of the area southeast of Timmins. Variation in local relief rarely exceeds 15 to 23 m, and extensive areas of wet muskeg are common in much of the area south of Timmins. The area to the southeast of Timmins is drained northward, primarily by the Redstone River and Night Hawk Lake (Pyke 1982).

Most of the area near Matachewan has rapid changes in elevation varying from 15 to 50 m. Large syenite and granite bodies rise above the level of the area, whereas volcanic rocks and diabase dikes form north-trending ridges. Cobalt Group sedimentary rocks provide the highest elevations in the region around Matachewan. The drainage in this region forms a trellis pattern following the north and northwest trends of the main system of joints and faults (Lovell 1967).

The area around Gowganda is one of moderate relief with a maximum of 120 m being attained immediately west of Flatstone Lake where a ridge of Nipissing gabbro reaches an elevation of 460 m asl. North-trending hills of similar elevation, and formed of Gowganda Formation rocks, occur immediately west of Gowganda. All of the drainage around Gowganda belongs to the north-flowing Montreal River system (McIlwaine 1978).

The southeast region of the study area is partly situated within the Cobalt plain. The area is composed of clayey and sandy lowlands interrupted by rocky uplands. Much of the area is nearly flat and underlain by glaciolacustrine clay-rich beds that were deposited in glacial lake Barlow–Ojibway.

Elevations range from 180 to 360 m asl. Most uplands are marked by prominent north-trending patterns of narrow valleys that are controlled either by faults, such as the Montreal River Fault system, or by joints in the Precambrian bedrock (Roed 1979a). Lakes are common physiographic features of the uplands and almost all shorelines are rocky or bouldery and very irregular. Many of the lakes are connected by narrow, poorly developed alluvial channels, which are characterized by rapids and low waterfalls, or by small linear ponds or lakes and organic depressions (Roed 1979a).

BEDROCK GEOLOGY

The oldest rocks in the study area are Neo- to Mesoarchean (2.5 to 2.9 Ga) age and belong to the Abitibi Subprovince of the Superior Province. Located in the southeast corner of the study area, rock units include granitic rocks of the Round Lake batholith and intrusive massive granodiorite and foliated tonalite suite rocks (Ontario Geological Survey 1991). Rock units in the northern part of the study area include mafic to intermediate to ultramafic metavolcanic rocks, felsic to intermediate metavolcanic rocks and massive granodiorite to granite. The southwest part of the study area is composed of Huronian Supergroup (including the Cobalt Group), foliated tonalite suite, mafic to ultramafic metavolcanic rocks, and Nipissing gabbro sills and dikes (Figure 19.2).

The southwestern part of the study area, around Gowganda, lies near the northwestern edge of the Cobalt Plain of the Southern Structural Province of the Canadian Shield. The exposed Archean rocks represent inliers in the Paleoproterozoic cover with the exception of the metavolcanic assemblage exposed within the Miller Lake gabbro basin. The rocks of the area are readily divisible into 4 major units as follows: 1) Paleoproterozoic gabbroic rocks (Nipissing gabbro); 2) Cobalt Group sedimentary rocks; 3) granitic intrusions; and 4) metavolcanic rocks with associated iron formation (McIlwaine 1978). The felsic plutonic rocks exposed in the area represent the extreme southwestern limit of the Round Lake batholith and are actually part of a large inlier in the Huronian Supergroup cover. Two distinct rock types are recognized in this region of the Round Lake batholith: quartz diorite and albite trondhjemite. Mesoproterozoic quartz diabase and olivine diabase dikes are the youngest rocks in the area.

The central part of the study area, near Matachewan, comprises rocks of every major division of the Precambrian stratigraphic column for northeastern Ontario. The oldest rocks in the area are Archean metavolcanic rocks and are overlain by tightly folded Timiskaming assemblage metasedimentary rocks. Both are cut by mafic and felsic intrusions. The intrusive rocks were subsequently cut by Paleoproterozoic diabase dikes. Flat-lying metasedimentary rocks of the Gowganda Formation overlie all of the above rocks and are intruded by a few late Nipissing gabbro dikes (Lovell 1967).

The northern part of the study area is underlain largely by Archean supracrustal rocks. These rocks include the Bartlett, Peterlong, Bowman, Geikie and Watabeag assemblages (Jackson and Fyon 1991). Three compositional classes of metavolcanic rocks have been recognized. These include 1) a calc-alkalic suite; 2) a tholeiitic suite, which includes iron-rich and magnesium-rich end members; and 3) a komatiitic suite. Large batholiths and stocks of felsic-intermediate composition intrude the supracrustal rocks. The most notable of these include the Watabeag batholith, which is located in the northeastern part of the study area, and the much smaller Adams, Blackstock, Geikie and Cairo stocks. Numerous syenitic intrusions and dikes, such as the Cairo stock, occur throughout the northern part of the study area. A north-trending succession of Proterozoic metasedimentary rocks occurs along the northeastern edge of the study area. These rocks belong to the Huronian Supergroup and consist of relatively flay-lying mudstone, wacke and conglomerate of the Gowganda Formation (Cobalt Group) (Ontario Geological Survey 1991).

The southeastern part of the study area comprises rocks of the Round Lake batholith, the Skead assemblage and conglomerate, wacke and mudstone of the Cobalt Group. The Round Lake batholith is a

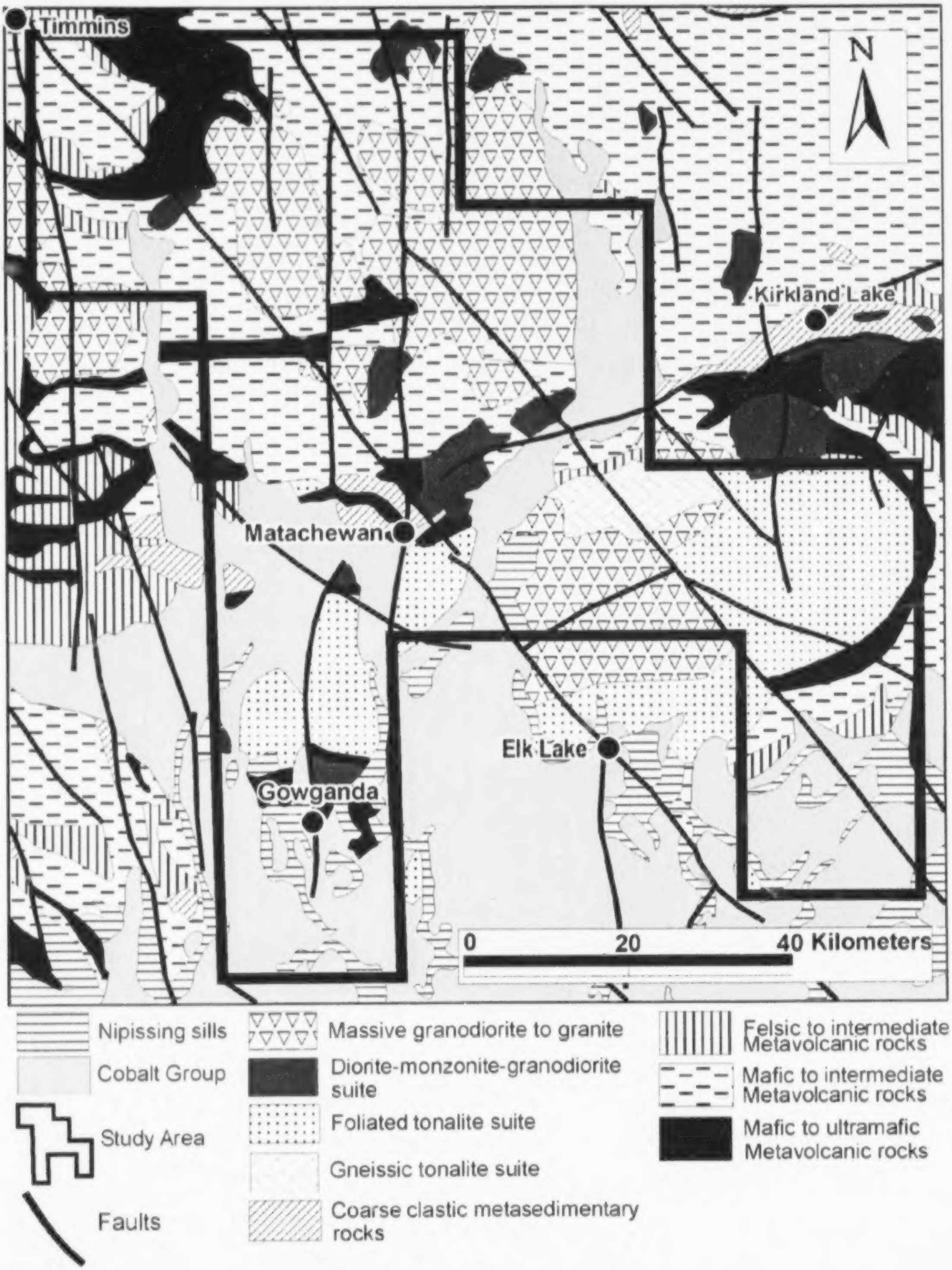
Timmins
N
Kirkland Lake
Matachewan
Elk Lake
Gowganda
0
20
40 Kilometers
Nipissing sills
Cobalt Group
Study Area
Faults
Massive granodiorite to granite
Diorite-monzonite-granodiorite suite
Foliated tonalite suite
Gneissic tonalite suite
Coarse clastic metasedimentary rocks
Felsic to intermediate Metavolcanic rocks
Mafic to intermediate Metavolcanic rocks
Mafic to ultramafic Metavolcanic rocks

Figure 19.2. Regional bedrock geology of study area.

40 by 80 km, elliptical, east-northeast-trending body. The batholith consists of 2 main phases: 1) an older, foliated to gneissic, hornblende-biotite tonalite-granodiorite phase; and 2) a younger weakly to unfoliated granodiorite-tonalite phase with quartz monzodiorite affinities. The Skead Assemblage wraps around the eastern and southern margins of the Round Lake batholith. The Skead assemblage is composed predominantly of calc-alkalic, felsic to intermediate metavolcanic rocks (Jackson and Fyon 1991).

Faults and joints in the bedrock are numerous and the presence of many faults is evident in the terrain. Parallel, northwest-trending fault systems are the most prominent ones in the study area and include the Cross Lake and Montreal River faults (Roed 1979a).

ECONOMIC GEOLOGY

Past-producing mines in the region include 1) the Texmont nickel-copper-platinum group element mine, which occurs in komatiitic rocks of the Bartlett assemblage along the boundary of Bartlett and Geikie townships (immediately to the southwest of Douglas township); 2) numerous mines associated with the Matachewan gold camp, including the Young–Davidson and the Matachewan Consolidated mines, which are located in Powell Township (Lovell 1967); and 3) the Ashley Gold Mine in northwestern Bannockburn Township, where gold is contained within quartz veins cutting sheared, highly altered mafic metavolcanic rocks (Bajc et al. 1996). In central Robertson township, the discovery, by Queenston Mining Inc., of base metal mineralization (copper-zinc) contained within felsic volcanic rocks (Jensen 1992) attests to the volcanogenic massive sulphide potential of the area (Bajc et al. 1996). The western extension of the Larder–Cadillac deformation zone within in the townships of Montrose, Bannockburn and Powell, shows a zone with high potential for gold mineralization (Jensen 1995).

QUATERNARY GEOLOGY

During the Wisconsin Episode, the study area was covered by glacial ice of the Laurentide Ice Sheet (Roed 1979a). In general, glacial ice advanced south to southwestward across the study area (Barnett 1992). Ice-flow indicators, such as glacial grooves and striae, chattermarks, *roches moutonnées*, crag-and-tail features and glacial flutings in areas of thick, continuous till, have been observed in the area (Bajc and Crabtree 2001). Together, these features indicate a fairly consistent late-glacial pattern of ice flow directed toward the south to southeast. However, the presence of crossing striae record a sequence of ice flow events that both predate and postdate the main ice-flow event. It has been proposed that 3 different stages of ice flow direction affected the region (Veillette 1986). The oldest, a west-southwest flow (230 to 270°) and a younger, south-southwest flow (180 to 220°) were overprinted by the latest regional south-southeast ice flow (130 to 170°) (Veillette 1986).

Glacial deposits present to the north and east of the Elk Lake region are thought to be primarily of Late Wisconsinan age (Roed 1979a). Advance of the Laurentide Ice Sheet across the area deposited a discontinuous cover of silty sand till (McClenaghan et al. 1999a). Most upland regions within the study area are characterized by bare bedrock or a thin discontinuous till cover with isolated pockets of thick till. There are, however, areas where extensive till cover masks the underlying bedrock forming gently undulating ground moraine. Till was deposited primarily by lodgement and/or meltout processes or as ice-marginal debris flow (Bajc and Crabtree 2001).

By approximately 10 000 years ago, the glacial front had receded to the current area of study. Extensive esker and deltaic complexes, kames and kettles and moraines were deposited and represent a major stillstand of the ice sheet (Roed 1979b). All of the eskers in the area are composed essentially of sand, gravel, pebbles and some cobbles (MacKean 1968). Deposits of glaciofluvial and glaciolacustrine sediments occur in structurally controlled valleys throughout the study area, as well as in broad basinal settings. Deposits of eolian sand and peat quite often cap the sediment sequence within these areas. The bedrock surface is covered by variable thicknesses of sediment that often ranges up to several tens of metres.

Approximately 9500 years ago, the ice front had receded well to the north of the study area. At that time, glacial Lake Barlow joined with Lake Ojibway to form Lake Barlow–Ojibway. Meltwater from the Elk Lake valley emptied into this lake along the western part of the New Liskeard lowland (Roed 1979a). Approximately 8700 years ago, barriers along the Lake Temiskaming valley were breached and Lake Barlow–Ojibway drained in several stages (Roed 1979b). Thick deposits of fine-grained glaciolacustrine sediments associated with glacial Lake Barlow–Ojibway are found within the southeastern part of the study area.

Recent deposits consist mainly of organic swamp deposits and lake sediments and are found throughout the study area (Born and Burbidge 1997).

REGIONAL SAMPLING SURVEY

The current regional modern alluvium survey, covering a total area of approximately 5500 km^2, was conducted in June, July and August 2003. A total of 317 modern alluvium, 6 till, 22 glaciofluvial sand and gravel and 12 beach deposit samples were collected. Access to sample locations was achieved by truck, ATV, boat, float plane and helicopter. The resulting distribution of collected samples provides excellent regional coverage. Regional overburden heavy mineral surveys provide data on the types, distribution and relative concentration of heavy minerals in a given region. The number of samples collected was predetermined by budget and time considerations, however, samples were collected over as broad an area as possible. The position of each sample was accurately recorded with a global positioning system (GPS) instrument set to North American Datum (NAD) 83 and 27 and using NTS 1:50 000 scale map sheets situated in UTM Zone 17.

Modern alluvium was chosen as the primary sampling media for this study as it provides a means of obtaining a fast, relatively inexpensive heavy mineral signature for individual drainage basins (Morris et al. 2000). Points of heavy mineral deposition within streams were targeted for sample collection. Sampling points included the deepest part of the channel; longitudinal and point bars; and boulder, log and vegetation traps (Morris et al. 2000). Material was sieved in the field using a 5 mm mesh screen and the finer fraction (<5 mm) was retained. Sample weight ranged from 10 to 20 kg. At some sites, larger samples were collected to compensate for either a high percentage of fine-sand or silt material in the sediment or the dilution of heavy mineral grains caused by a high percentage of organic material. The <5 mm fraction of the sample was sent for heavy mineral processing to separate possible kimberlite and other indicator minerals. Where possible, approximately 50 pebbles were collected from the coarser (>5 mm) fraction at each sample site for pebble lithology classification. Pebble lithologies classified to date indicate that, typically, stream deposits are locally derived. In addition, at each site, a small portion of the stream sediment was panned and the resultant "fine-fraction" concentrate retained.

At each sample location, a site description consisting of observations on a) genesis of material, stream flow and depth; b) surface expression; c) slope inclination and aspect; d) drainage; e) vegetation type and state; f) glacial features; g) anthropogenic factors; h) material description consisting of: i) texture; ii) structure; iii) bar form, iv) clast size, abundance, shape and type; and e) diagrams and additional comments, was completed. Photographs were taken at several sites.

Results from the study are expected to be released in the spring of 2004.

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20. Project Unit 03-019. Kakagi Lake Area High Density Regional Lake Sediment and Water Survey, Northwestern Ontario

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INTRODUCTION

Field work for a high-density lake sediment and water geochemical survey in the Kakagi Lake area of northwestern Ontario was carried out from June 3 to June 30, 2003. The survey area is located approximately 100 km southeast of Kenora and is represented on National Topographic System (NTS) 1:50 000 scale map sheets 52 F/3, 52 F/4, 52 F/5 and portions of 52 F/6 and 52 F/12. Lake sediment and/or water samples were collected at 1358 sites, for an average density of 1 sample per 2.7 km^2.

The Kakagi Lake area was selected for this type of survey for reasons including client interest, geology with favourable mineral potential and a lack of detailed geochemical exploration data for the region. The present survey lies immediately to the southwest of the Eagle Lake lake sediment survey carried out in 2002 (Russell 2002). Part of the National Geochemical Reconnaissance (NGR) lake sediment program carried out by the Geological Survey of Canada in the 1970s covered the current survey area (Hornbrook and Friske 1989), but at a much broader scale (an average of 1 sample per 13 km^2). The results of the current program will provide new regional geochemical data at a relatively high resolution.

REGIONAL GEOLOGIC SETTING

Bedrock Geology

The geology of the survey area is represented at a scale of 1:253 440 on an Ontario Geological Survey (OGS) Geological Compilation Series map (Blackburn 1981). Much of the greenstone belt within the survey area has been mapped at a scale of 1:31 680 (Davies 1973; Davies and Morin 1976; Edwards 1980, 1983a, 1983b). Berger (1991) and Smith (1993) mapped the eastern portion of the greenstone belt in the Vista Lake–Manitou Stretch area at a scale of 1:20 000. The Lobstick Bay–Berry Lake area was mapped by Johns (1987) at a scale of 1: 15 840.

The present survey lies within the western Wabigoon Subprovince, a granite-greenstone terrane of the Superior Province, and covers most of the Kakagi–Rowan Lakes greenstone belt. The eastern part of the survey area encompasses the southwestern end of the Manitou Lakes greenstone belt.

The Kakagi–Rowan Lakes greenstone belt is divided into 2 domains, which are separated by the northwest-trending Pipestone–Cameron deformation zone (PCDZ). Rocks on either side of the

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Summary of Field Work and Other Activities 2003, Ontario Geological Survey, Open File Report 6120, p.20-1 to 20-7.

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deformation zone are generally not correlated with each other (Johns 1987), though Davis and Edwards (1982, 1986) suggest that the intermediate metavolcanic rocks of the Stephen Lake formation to the southwest of the PCDZ and the Berry Creek formation (also known as Berry River formation) to the north may be correlative based on REE patterns and geochronology.

Northeast of the PCDZ, the stratigraphic sequence consists of lower mafic metavolcanic units (coeval Rowan Lake and Populus Lake volcanics, Brooks Lake volcanics) a middle mixed felsic to intermediate metavolcanic unit (Dogpaw Lake and Cameron Lake volcanics) (Blackburn et al. 1991; G.W. Johns, OGS, personal communication, 2003). The lower mafic units are pillowed to massive tholeiitic flows, mixed with calc-alkaline pyroclastic rocks in the upper part of the sequence. The upper contact of the Rowan Lake volcanics is interbedded with the overlying Dogpaw Lake volcanics (calc-alkalic and tholeiitic pillowed, massive and amygdaloidal flows, heterolithic breccia and lapilli-tuff conglomerate), and conformable with the lower unit of the overlying Cameron Lake volcanics (calc-alkalic and tholeiitic massive to pillowed flows, pyroclastic rocks). The upper unit of the Cameron Lake volcanics consists of andesitic pillowed, amygdaloidal and bedded rocks. The Berry Creek formation occurs along the north shore of Lobstick Bay, Lake of the Woods, and extends west out of the survey area. Part of the Warclub group, it consists of dacitic pyroclastic rocks and is interbedded with Warclub group metasedimentary rocks (Johns 1987).

To the southwest of the PCDZ, the stratigraphy follows a similar pattern of lower mafic units (coeval Snake Bay and Katimiagamak groups) overlain by an intermediate metavolcanic sequence (Kakagi Lake group) (Blackburn et al. 1991; Davis and Edwards 1982, 1986). The Snake Bay group consists of an upper formation of iron-tholeiite flows and a lower formation of magnesium-tholeiite flows. The Katimiagamak group is composed of pillowed and massive amygdaloidal iron-tholeiite flows. The Kakagi Lake group consists of andesitic and dacitic flows, pyroclastic rocks, and associated sediments (Davis and Edwards 1986), and has been subdivided into formations (South Kakagi Lake, East Kakagi Lake, Emm Bay, Cedartree Lake, Stephen Lake (Blackburn et al. 1991)) on the basis of clast size and texture (Davis and Edwards 1982).

At the eastern side of the survey area, the Manitou Lake greenstone belt consists of the massive to pillowed magnesium- and iron-tholeiitic and komatiitic rocks of the Wapageisi group, the conformably overlying calc-alkalic pyroclastic rocks, minor mafic flows and associated sediments of the intermediate Manitou Lake metavolcanic group, and the unconformably overlying arkosic wacke, siltstone and mudstone of the Thompson Bay and Esox Lake sediments (Blackburn et al. 1991). In this area, the PCDZ changes direction to trend northeast along the Manitou lakes towards Dinorwic, Ontario.

Mafic to ultramafic intrusions are present in nearly all stratigraphic units, though they are most predominant in the Katimiagamak and Rowan Lake volcanics (of the lower mafic units), and the Kakagi Lake group (upper intermediate units). These intrusions are considered to be synvolcanic based on petrology and geochronology (Blackburn et al. 1991).

The supracrustal rocks within the survey area are intrusively bounded by a number of felsic plutonic rocks: The Dryberry batholith to the north, Atikwa batholith to the northeast, Irene–Eltrut Lakes complex to the southeast, Rainy Lake batholithic complex to the south, and the Sabaskong batholith to the southwest. As well, a number of smaller felsic intrusive rocks occur within the greenstone belts, some of which are favourable targets for mineralization. The Phinney–Dash Lakes Complex is a subvolcanic felsic intrusion, which overlies the Katimiagamak volcanics (Davis and Edwards 1982), and may represent a favourable target for Kuroko-type gold-silver-volcanogenic massive sulphide mineralization (Edwards 1983a). The Stephen Lake stock is a late-tectonic quartz-diorite stock, which intrudes the intermediate Kakagi Lake group, and shows favourable gold and molybdenum mineralization (Davis and Edwards 1986), as well as similarities to porphyry copper type intrusions in western North America (Davies and Morin 1976).

Physiography and Surficial Geology

The most detailed surficial mapping for the survey area was completed for the Geological Survey of Canada at a scale of 1:100 000 (Minning 1988). Surficial materials across the survey area are described in Minning (1988) as thin and sporadic, occurring primarily as shallow deposits in bedrock depressions or patches of till covering the lee side of rock knobs. These materials are estimated to cover less than 15% of the survey area, and due to their thin and sporadic nature, they are not expected to have any significant influence on the surficial geochemistry of the region.

Relief in the survey area varies from approximately 325 to 450 m asl. Topography is controlled by structural and lithological bedrock features, with much of the bedrock in the area having been glacially modified and showing rounded, polished, and striated stoss and lee rock forms (Minning 1988). Surficial hydrology is strongly influenced by the physiography of the underlying bedrock. At a regional scale, the distribution of lakes is very closely related to the irregular contacts of the various bedrock lithological units.

SAMPLING METHODS

Sampling of organic lake sediments was performed using a float-equipped Bell 206B helicopter. Where access was available and the number of samples warranted, some lakes were sampled from a 17-foot aluminium boat with a 25-horsepower motor. An overall average of 13.4 lakes were sampled for each hour of helicopter time. The samples were collected using a gravity corer designed by the OGS. Samples were taken from depths greater than 20 cm below the sediment–water interface (SWI) in order to minimize or avoid anthropogenic influences and SWI effects. These deeper sediments more accurately reflect geochemical effects, which may be traced back to the local geology. The samples were extruded from the collection tube into breathable fabric bags and then placed in a sealable plastic bag until the end of the sampling run.

Lake water samples were taken upon landing at the sample site, prior to the collection of sediment samples. On shallow lakes (<3 m), the samples were collected at 0.5 m below the water surface; on deeper lakes (>3 m), the samples were collected at a depth of 2 m. A semi-automated water sampling apparatus, developed by the OGS and consisting of a pump, a YSI multiparameter water quality analyzer (for measurement of parameters such as pH, temperature and conductivity), a sample bottle tray and a variety of hoses and valves, was used for sample collection. Lake water is pumped through the system in order to purge it prior to the collection of a sample and the recording of water quality data. The water samples were kept cool immediately following collection and were processed (filtered and acidified) within 24 hours of collection. Owing to technical difficulties, water samples 1 to 72 (inclusive) were processed within 96 hours of collection, while samples 73 to 472 (inclusive) were processed within 72 hours of collection. These samples will be analyzed in sequence with the rest of the samples, however their data will be treated separately from the rest of the samples. YSI water quality data within this series is not affected.

Sample site locations were recorded using a global positioning system (GPS) receiver mounted in the cockpit of the helicopter. Sediment sample information and descriptions were recorded on standardized forms and later entered into a Microsoft® Access database. Water quality data was recorded using a hand-held data logger and transferred to a computer at the end of each sampling run.

SAMPLE PREPARATION AND ANALYTICAL METHODS

Lake sediment samples were partially air dried in porous collection bags while in the field. Upon arrival at the laboratory, the samples were freeze dried, partially pulverized in a ceramic ring mill and sieved to obtain the −80 mesh (<177 µm) size fraction. Laboratory analysis includes nitric–aqua regia digestion followed by inductively coupled plasma mass spectrometry (ICP–MS) and inductively coupled plasma optical emission spectrometry (ICP–OES) for the determination of approximately 50 trace and major elements. Nitric–aqua regia digestion attacks all sample matrix constituents except for silicate minerals and is, therefore, considered a non-selective, relatively strong partial extractant. Approximately 15 g of sample pulp are pressed into briquettes prior to analysis by instrumental neutron activation analysis (INAA) for gold and 34 other elements. Loss on ignition (LOI) is determined at 500°C using an automated gravimetric technique. Quality control is monitored through the use of certified reference materials placed regularly through the sample sequence and randomly taken sample pulp duplicates.

Water samples were passed through 0.45 µm syringe filters and acidified to approximately 1% ultrapure nitric acid. Analysis of water was completed by direct aspiration ICP–MS to determine approximately 50 elements. Quality of the analyses is monitored through the use of blanks, National Research Council certified reference standard SLRS-4, and random sample duplicates.

PRELIMINARY RESULTS

Electrical conductivity (EC) values in lake waters in the survey area range from 12 to 458 µS/cm, averaging 59 µS/cm. Figure 20.1 shows the distribution of conductivity in lake water across the study area. As surficial cover in the area is not extensive, bedrock geology is the primary factor contributing to these values. Values in the 90th percentile of the data set (>111 µS/cm) occur in areas underlain by or in close proximity to bedrock mapped as either metavolcanic or metasedimentary rocks. The lower values of the data set (<50th percentile) occur in primarily granitic bedrock areas. The highest EC value in the data set (458 µS/cm) occurs in a lake on the southwest side of Highway 71 and downhill from a roadcut on the northeast side of the highway, which the author observed to have a more pronounced gossanous appearance than the surrounding bedrock.

Values for pH in lake waters range from 5.09 to 8.91, with nearly all well within the range of naturally occurring freshwater lakes (Figure 20.2). The average value of pH in the area was 6.80, likely resulting from the lowered buffering capacity, and therefore increased acidity, of lakes underlain by felsic intrusive rocks compared to those lakes underlain by altered metavolcanic rocks.

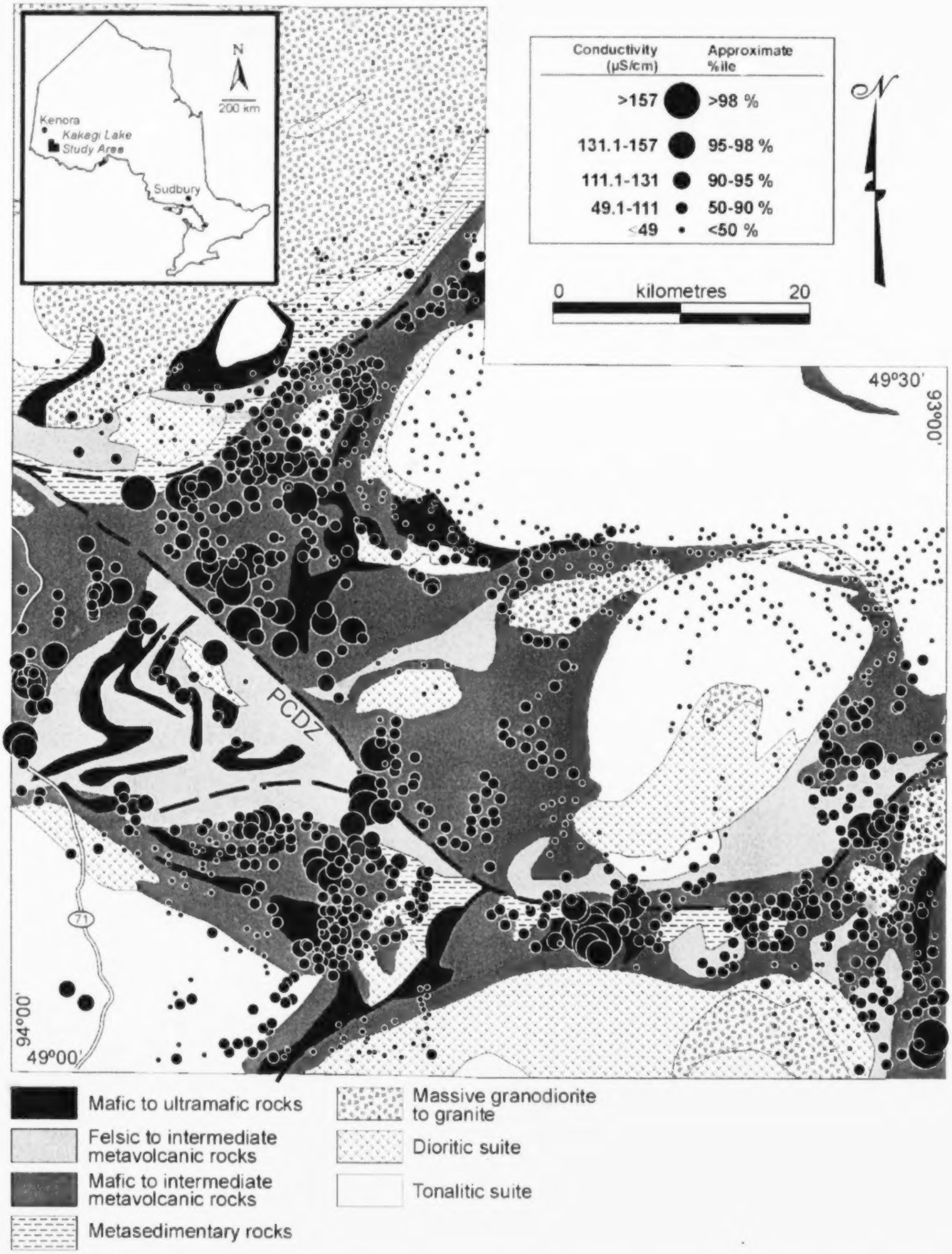
Conductivity (µS/cm)
Approximate %ile
>157 >98 %
131.1-157 95-98 %
111.1-131 90-95 %
49.1-111 50-90 %
<49 <50 %
N
0 kilometres 20
200 km
Kenora
Kakagi Lake Study Area
Sudbury
49°30'
93°00'
94°00'
49°00'
PCDZ
71
Mafic to ultramafic rocks
Felsic to intermediate metavolcanic rocks
Mafic to intermediate metavolcanic rocks
Metasedimentary rocks
Massive granodiorite to granite
Dioritic suite
Tonalitic suite

Figure 20.1. Generalized bedrock geology and electrical conductivity in lake waters. Geology *after* Ontario Geological Survey (1991).

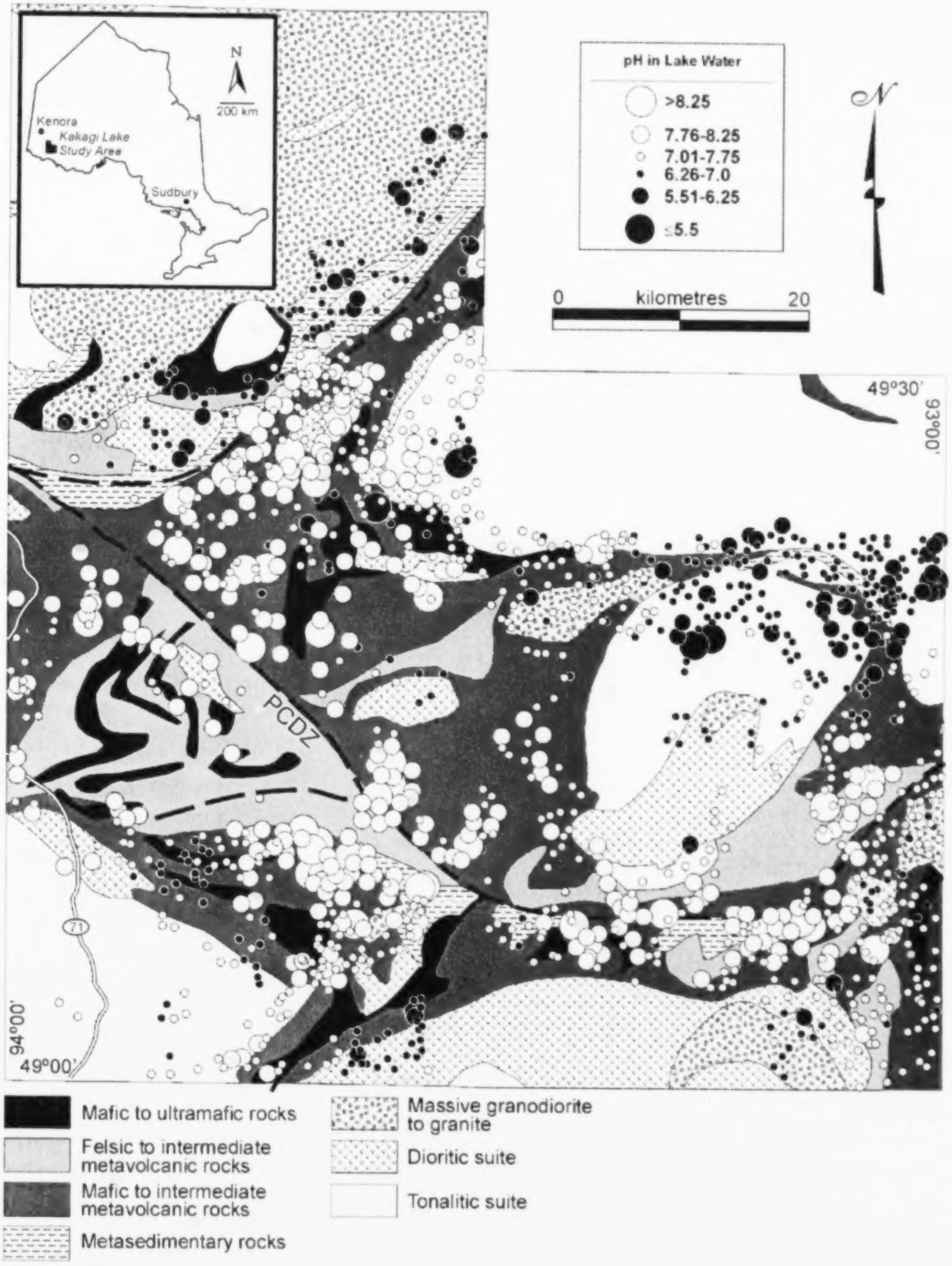
N
200 km
Kenora
Kakagi Lake
Study Area
Sudbury
pH in Lake Water
>8.25
7.76-8.25
7.01-7.75
6.26-7.0
5.51-6.25
≤5.5
N
0
kilometres
20
49°30'
93°00'
PCDZ
71
94°00'
49°00'
Mafic to ultramafic rocks
Felsic to intermediate metavolcanic rocks
Mafic to intermediate metavolcanic rocks
Metasedimentary rocks
Massive granodiorite to granite
Dioritic suite
Tonalitic suite

Figure 20.2. Generalized bedrock geology and pH in lake waters. Geology *after* Ontario Geological Survey (1991).

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21. Project Unit 03-018. Central Swayze Area High Density Regional Lake Sediment and Water Geochemical Survey, Northeastern Ontario

P.A. Takats[1]

[1]Sedimentary Geoscience Section, Ontario Geological Survey

INTRODUCTION

A helicopter-supported regional lake sediment and water geochemical survey of the central Swayze greenstone belt area was conducted by staff of the Ontario Geological Survey (OGS) from July 9 to July 28, 2003. The survey area is located approximately 290 km northwest of Sudbury, Ontario (Figure 21.1). The project area encompasses the southwestern portion of the Swayze greenstone belt that is bound by Ivanhoe and Horwood lakes to the north, and Biscotasi Lake and the Wakami Provincial Park to the south. The Swayze greenstone belt is the westward extension of the Abitibi greenstone belt and covers an area of approximately 8000 km^2. Samples were collected from a 5265 km^2 region that encompasses portions of the area represented on National Topographic System (NTS) map sheets 41 O/8, 41 O/9, 41 O/10, 41 O/15, and 41 O/16. Lake sediment and/or water samples were collected at 1398 sites for an average density of 1 sample per 3.8 km^2. This lake water and sediment survey completes the second year of a three-year project to generate geochemical data for the Swayze greenstone belt. The south Swayze area was surveyed during 2002 (Jackson 2002). The Swayze greenstone belt was selected for this type of geochemical survey because of its high potential for base and precious metal mineralization and because lake sediment/water geochemistry is an effective and expeditious method to assess the regional mineral potential of an area.

BEDROCK GEOLOGY

The Swayze greenstone belt (SGB) is located in the western Abitibi Subprovince of the Superior Province. The Swayze greenstone belt is bound on the north by the Nat River granitoid complex, on the west by the Kapuskasing structural zone (KSZ), on the south by the Ramsey–Algoma granitoid complex and on the east by the Kenogamissi granitoid complex. The SGB is connected to the Abitibi greenstone belt by a narrow band of metasedimentary and metavolcanic rocks that wrap around the northern and southern margins of the Kenogamissi granitoid complex (Jackson and Fyon 1991).

Massive peridotite, pyroxenite and dunite intrusions are common within the SGB. These ultramafic rocks are also spatially related to polysutured and spinifex textured komatiite volcanic flows (Heather 2001). Mafic to intermediate metavolcanic and synvolcanic intrusive rocks are widely dispersed throughout the belt. These include iron-tholeiitic basalts, magnesium-tholeiitic basalts, calc-alkalic basalts, and gabbro and/or diorite sills and dikes. The metavolcanic rocks consist of massive, pillowed, pillow breccia, variolitic and amygdaloidal flows. Several large sequences of felsic to intermediate metavolcanic rocks also occur within the SGB and consist of massive to pillowed flows and associated pyroclastic rocks. Chemical metasedimentary rocks consisting of sulphide- and carbonate-facies iron formations occur within most of the metavolcanic sequences within the SGB. Older sequences of clastic

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Summary of Field Work and Other Activities 2003, Ontario Geological Survey, Open File Report 6120, p.21-1 to 21-7.

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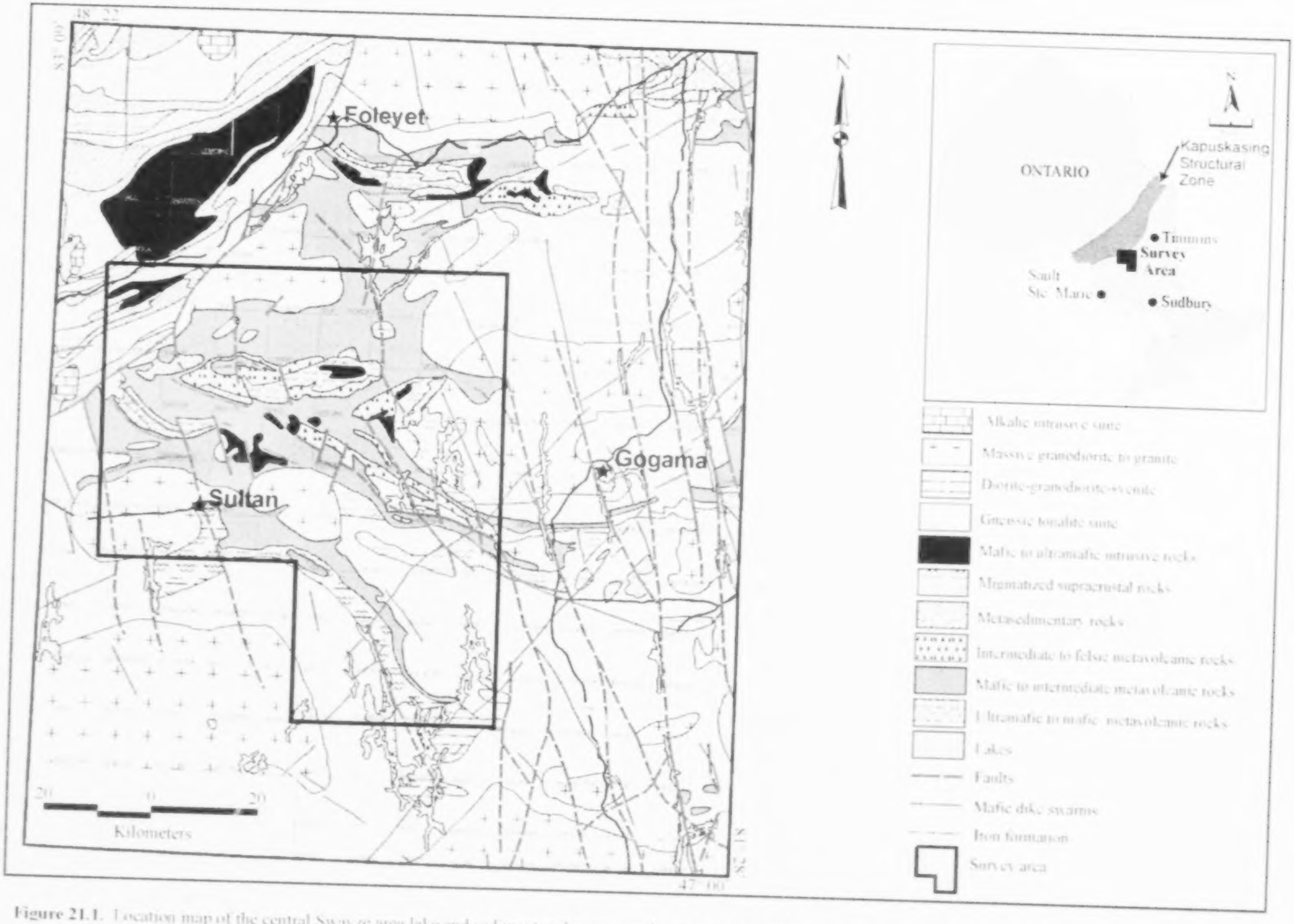
48°22'
83°00'
Foleyet
Gogama
Sultan
20
0
20
Kilometers
81°28'
47°00'
N
ONTARIO
N
Kapuskasing Structural Zone
Timmins
Survey Area
Sault Ste. Marie
Sudbury
Alkalic intrusive suite
Massive granodiorite to granite
Diorite-granodiorite-syenite
Gneissic tonalite suite
Mafic to ultramafic intrusive rocks
Migmatized supracrustal rocks
Metasedimentary rocks
Intermediate to felsic metavolcanic rocks
Mafic to intermediate metavolcanic rocks
Ultramafic to mafic metavolcanic rocks
Lakes
Faults
Mafic dike swarms
Iron formation
Survey area

Figure 21.1. Location map of the central Swayze area lake and sediment and water geochemical survey. Bedrock geology *after* Ontario Geological Survey (1991).

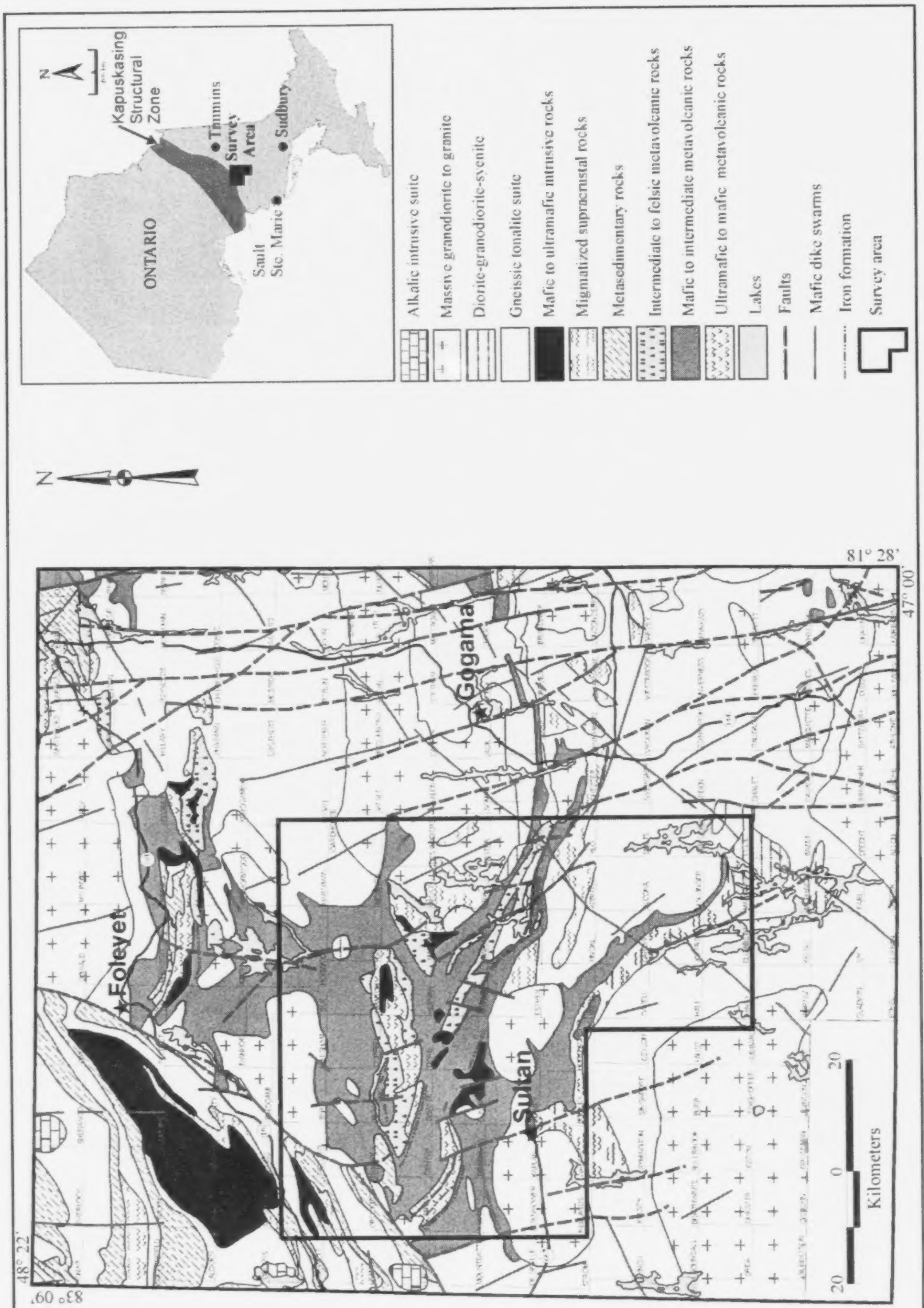
48° 22'
83° 09'
81° 28'
47° 00'
Foleyet
Gogama
Sultan
N
20
0
20
Kilometers
ONTARIO
Kapuskasing Structural Zone
Timmins
Survey Area
Sudbury
Sault Ste. Marie
N
Alkalic intrusive suite
Massive granodiorite to granite
Diorite-granodiorite-syenite
Gneissic tonalite suite
Mafic to ultramafic intrusive rocks
Migmatized supracrustal rocks
Metasedimentary rocks
Intermediate to felsic metavolcanic rocks
Mafic to intermediate metavolcanic rocks
Ultramafic to mafic metavolcanic rocks
Lakes
Faults
Mafic dike swarms
Iron formation
Survey area

Figure 21.1. Location map of the central Swayze area lake and sediment and water geochemical survey. Bedrock geology *after* Ontario Geological Survey (1991).

metasedimentary rocks in the SGB contain a close temporal and tectonic relationship to the metavolcanic rocks in the belt (Heather 1993). Younger sequences of clastic metasedimentary rocks in the SGB unconformably overlie the older supracrustal sequences and are likely correlative with the Timiskaming assemblage rocks in the Abitibi greenstone belt (Jackson and Fyon 1991). The present geochemical survey covers a major portion of the metavolcanic and metasedimentary rocks within the SGB extending from the Kapuskasing structural zone in the west, towards Gogama in the east (*see* Figure 21.1). The SGB has a high potential for mesothermal gold, volcanogenic massive sulphide copper-zinc-lead and mafic to ultramafic intrusive and extrusive related nickel-copper±platinum group element (PGE) mineralization (Heather 1993).

PHYSIOGRAPHY AND QUATERNARY GEOLOGY

The terrain of the central Swayze area is characterized by low to moderate relief. Low relief is typical over glaciofluvial and eolian deposits and moderate relief is prevalent in morainal and bedrock dominated terrain. Elevations in the area range from 340 to 550 m asl.

A regional compilation of the Quaternary geology (Barnett, Henry and Babuin 1991) indicates that most of the bedrock in the study area is covered by a thin veneer of discontinuous drift (Figure 21.2). There are, however, several significant Quaternary features in the area: a glaciofluvial ice contact deposit with a morainal crest that runs to the south of and parallel to Hwy 667 from Sultan to Chapleau; a major till deposit south of the CPR railway between Sultan and Ramsey; and a large glaciolacustrine deposit in the central part of the survey area located west of Rice Lake. Several south-trending esker complexes are also located within the area, predominantly in the northwest corner.

SAMPLING METHODS

Where possible, organic lake sediment and water samples were collected at each lake site by two-person teams using a float-equipped helicopter. If a site contained no organic component (e.g., sand and/or clay), only a water sample was taken. The organic sediment was collected in a gravity corer, designed by the OGS, which was lowered from the helicopter float and then pulled to surface. The collected sediment was then deposited into a sample bag. The upper 20 cm of the sample core was discarded to avoid anthropogenic bias in the geochemical data and to avoid water–sediment interface effects (i.e., increased manganese due to anoxic conditions that result in secondary accumulation of base metals). The sediment below the 20 cm depth better reflects the natural element abundance that may be attributed to the local geology. Each sample was then sealed in an airtight plastic bag to prevent cross-contamination among the samples.

A semi-automated water sampling apparatus, developed by the OGS, was utilized for water collection. Lake water samples were collected at a depth of 0.5 m, below surface, from shallow lakes (<3 m deep) and at a depth of 2 m from deep lakes (>3 m) with a weighted water intake hose. The on-board apparatus consisted of a pump, a flow cell (for measurement of parameters such as pH, conductivity, oxidation-reduction potential and dissolved oxygen), a sample bottle tray and various hoses and pinch valves. Water was pumped from the lake and allowed to purge the sampling system prior to collection of a water sample and the recording of water quality parameters. Water samples were kept cool after collection and processed (filtered and acidified) within 24 hours of collection.

At each site, sediment descriptions and observations were recorded on standardized forms and entered into a computer database at the end of each day. The pH, temperature, conductivity, oxidation-reduction potential and dissolved oxygen of the water samples was recorded on a YSI water quality analyzer and a waypoint for the sample sites was taken using a global positioning system (GPS).

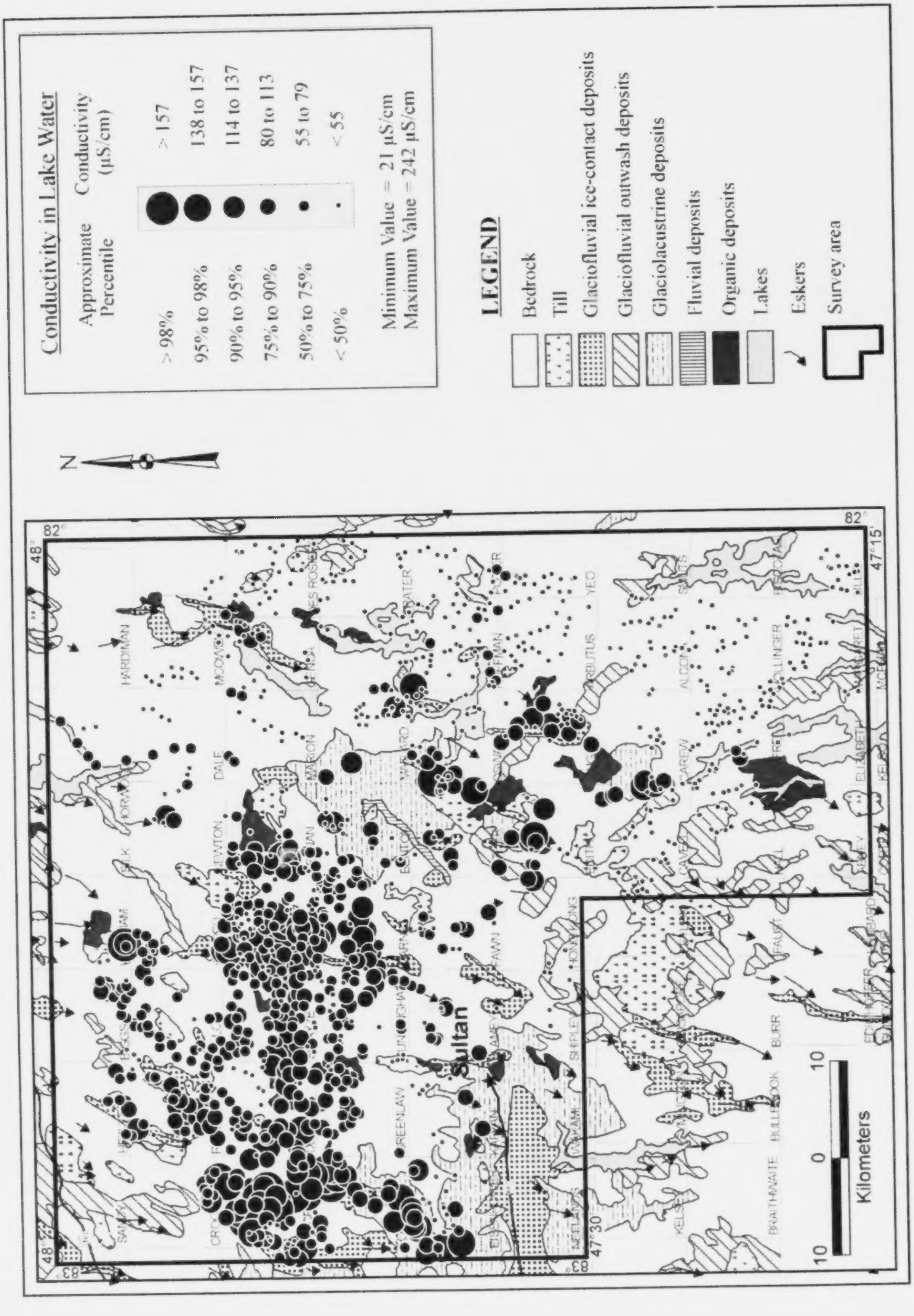
Conductivity in Lake Water
Approximate Percentile
Conductivity (µS/cm)
> 98%
> 157
95% to 98%
138 to 157
90% to 95%
114 to 137
75% to 90%
80 to 113
50% to 75%
55 to 79
< 50%
< 55
Minimum Value = 21 µS/cm
Maximum Value = 242 µS/cm
LEGEND
Bedrock
Till
Glaciofluvial ice-contact deposits
Glaciofluvial outwash deposits
Glaciolacustrine deposits
Fluvial deposits
Organic deposits
Lakes
Eskers
Survey area
N
Kilometers
10
0
10
48°
82°
83°
47°30'
47°15'
Sultan
HARDIMAN
DALE
MARION
KELSO
BRAITHWAITE
BULLBROOK
BURR
GREENLAW
YEO
ALCORN
ELIZABETH

Figure 21.2. Generalized Quaternary geology and electrical conductivity in lake waters of the central Swayze survey area. Quaternary geology *after* Barnett, Henry and Babuin (1991).

SAMPLE PREPARATION AND ANALYTICAL PROGRAM

The organic lake sediments were collected in breathable fabric sample bag and partially air-dried at the base camp. Upon arrival at the OGS, the samples were further air-dried, then freeze-dried, partially pulverized and sieved to attain a –80 (<177 μm) mesh size fraction. Laboratory analysis of the –80 mesh fraction of the organic sediments will include modified-aqua regia digestion of 1 g of sample material followed by inductively coupled plasma mass spectrometry (ICP–MS) and inductively coupled plasma optical emission spectrometry (ICP–OES) to determine approximately 50 trace elements. The modified-aqua regia digestion technique attacks all the matrix constituents in the sample except for the silicate minerals and is, therefore, considered a nonselective, relatively strong partial extractant.

For each sample, approximately 15 g of prepared material will be pressed into briquettes and submitted for analysis by instrumental neutron activation (INAA) for gold and a suite of 33 other elements. Duplicates of samples and certified reference materials will be used to monitor the quality control of all analyses. Loss on ignition (LOI) is determined at 500°C in an oxygen atmosphere, using an automated gravimetric technique.

The water samples were filtered through 0.45 μm syringe filters and acidified to 1% ultrapure nitric acid within 24 hours of collection. Approximately 50 elements including major cation and anion species will be determined using ICP–MS (direct aspiration). Sample duplicates, blanks and the SLRS-4 certified reference standard will be used to monitor the quality control of the water analyses.

PRELIMINARY RESULTS

The average electrical conductivity (EC) for surface waters sampled from the survey is 63 μS/cm with values ranging from 21 to 242 μS/cm. Figure 21.2 illustrates the range of EC values across the study area. The EC values are plotted on a base map of the generalized Quaternary geology of the central Swayze area (Barnett et al. 1991). In general, high electrical conductivity of lake waters in uncontaminated shield terrain is attributable to dissolved carbonate minerals from surficial sand and gravel deposits. Most of the higher EC values collected from the current survey occur over areas of glaciofluvial and glaciolacustrine deposits present in the northwestern section.

The pH of the surface waters ranged from 4.02 to 9.53 with an average pH of 7.34. The pH of surface waters for the study area is shown on Figure 21.3 plotted on a base map of generalized bedrock geology (Ontario Geological Survey 1991). Many of the more alkaline lakes occur with the higher EC values in the northwestern section of the survey area. The presence of more alkaline conditions with higher EC values indicates probable dissolved carbonate minerals in the waters derived from the underlying glaciofluvial and glaciolacustrine deposits. Lake waters with neutral to acidic pH values are underlain by intermediate to felsic intrusive complexes in areas with thin drift cover.

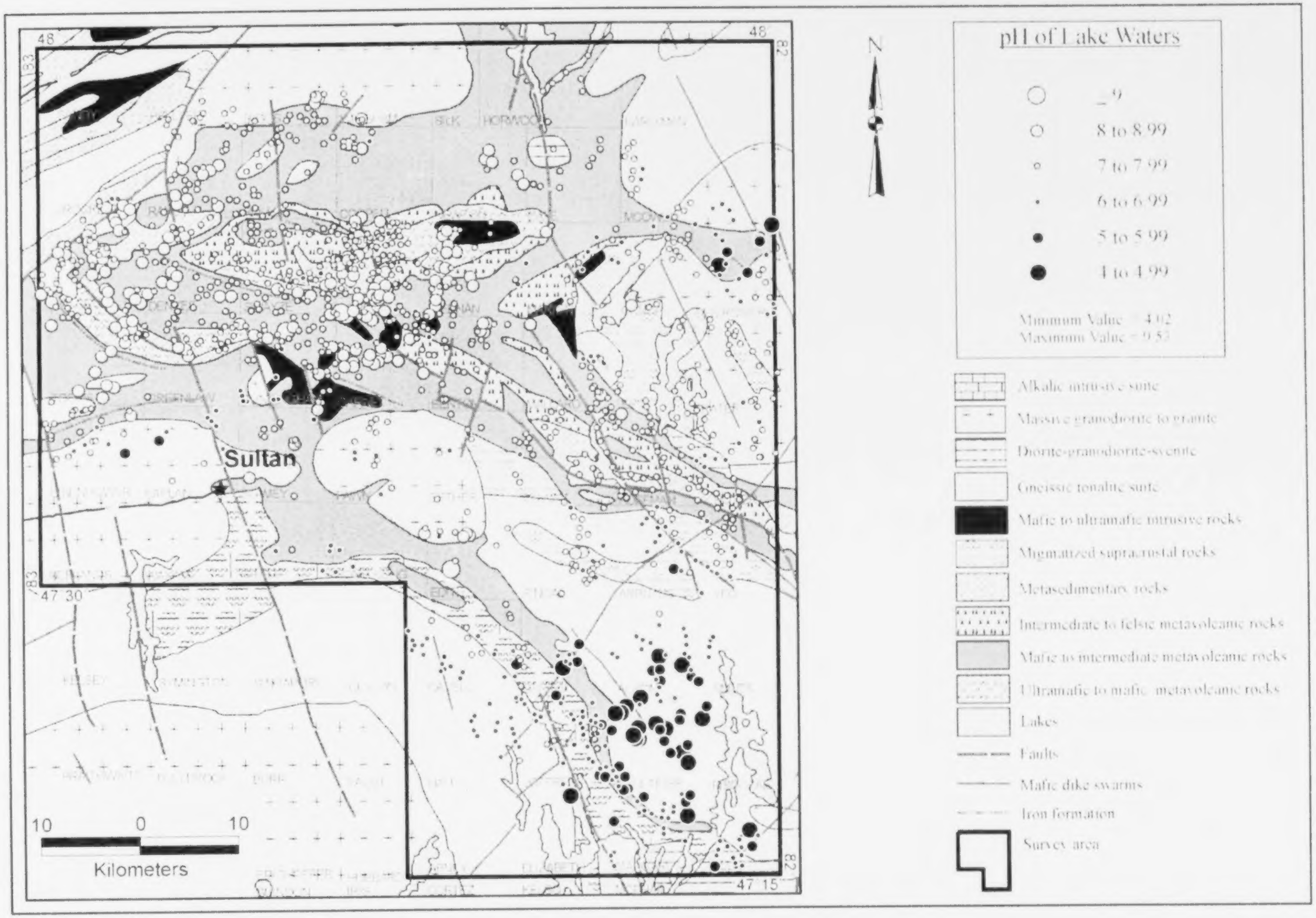
pH of Lake Waters
≥9
8 to 8.99
7 to 7.99
6 to 6.99
5 to 5.99
4 to 4.99
Minimum Value = 4.02
Maximum Value = 9.53
Alkalic intrusive suite
Massive granodiorite to granite
Diorite-granodiorite-syenite
Gneissic tonalite suite
Mafic to ultramafic intrusive rocks
Migmatized supracrustal rocks
Metasedimentary rocks
Intermediate to felsic metavolcanic rocks
Mafic to intermediate metavolcanic rocks
Ultramafic to mafic metavolcanic rocks
Lakes
Faults
Mafic dike swarms
Iron formation
Survey area
N
Sultan
10
0
10
Kilometers
48
82
83
47 30
47 15

Figure 21.3. Generalized bedrock geology and pH in lake waters of the central Swayze survey area. Bedrock geology *after* Ontario Geological Survey (1991).

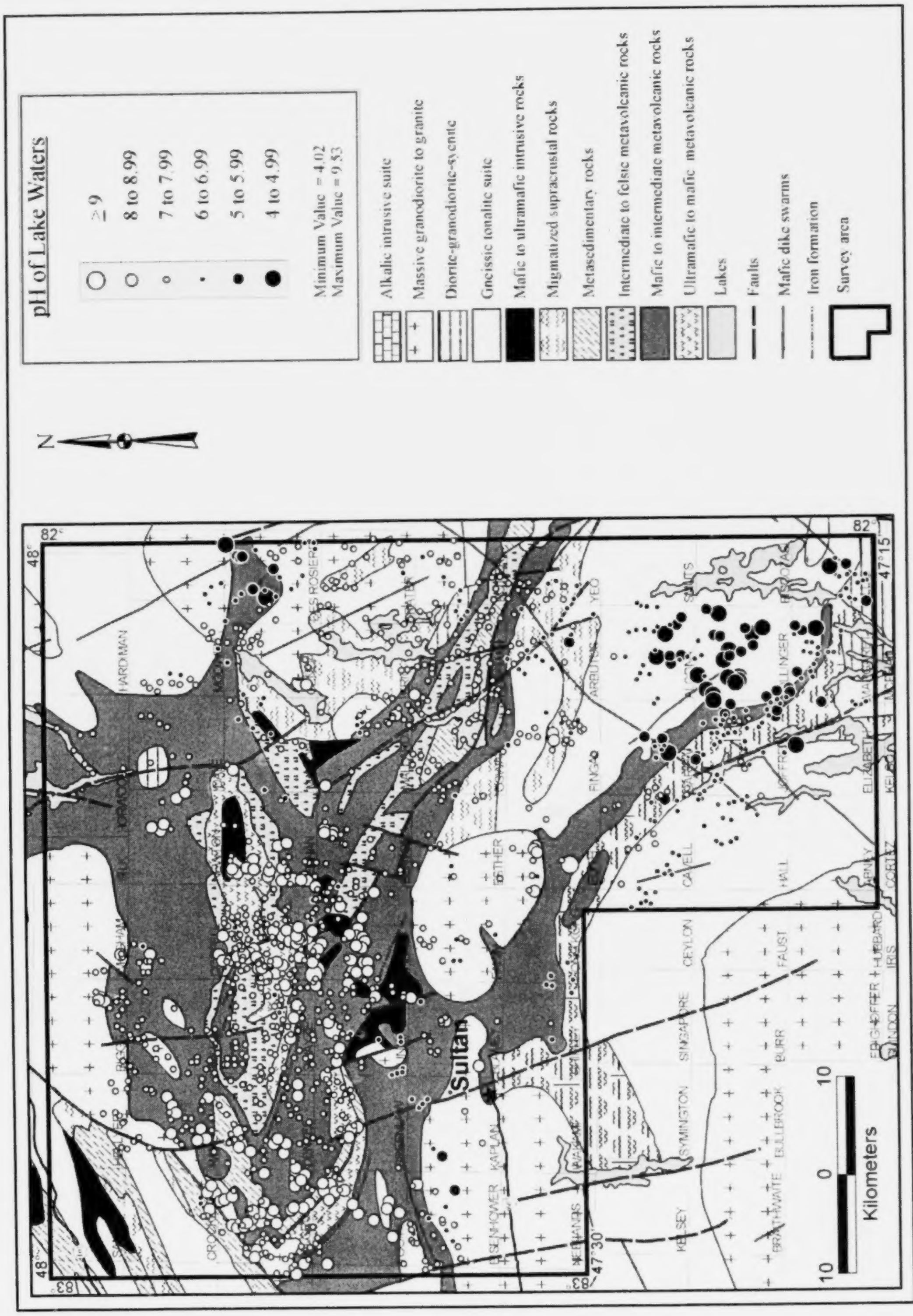
pH of Lake Waters
≥9
8 to 8.99
7 to 7.99
6 to 6.99
5 to 5.99
4 to 4.99
Minimum Value = 4.02
Maximum Value = 9.53
N
Alkalic intrusive suite
Massive granodiorite to granite
Diorite-granodiorite-syenite
Gneissic tonalite suite
Mafic to ultramafic intrusive rocks
Migmatized supracrustal rocks
Metasedimentary rocks
Intermediate to felsic metavolcanic rocks
Mafic to intermediate metavolcanic rocks
Ultramafic to mafic metavolcanic rocks
Lakes
Faults
Mafic dike swarms
Iron formation
Survey area
48°
82°
83°
47°30'
47°15'
Sultan
HARDMAN
DES ROSIERS
YEO
ARBUTUS
FINGAL
ELIZABETH
CAVELL
HALL
CORTEZ
CEYLON
FAUST
IRIS
HUBBARD
SINGAPORE
BURR
SYMINGTON
BULLBROOK
KAPLAN
EISENHOWER
KELSEY
BRAITHWAITE
10
0
10
Kilometers

Figure 21.3. Generalized bedrock geology and pH in lake waters of the central Swayze survey area. Bedrock geology *after* Ontario Geological Survey (1991).

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22. Project Unit 99-318. Deep Penetrating Geochemistry: Full-Scale Field Testing of Geochemical Exploration Methods over a Blind, Deeply Covered Volcanogenic Massive Sulphide(?) Target

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[2]Terrain Sciences Division, Geological Survey of Canada, Ottawa, Ontario
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INTRODUCTION

As part of an Ontario Mineral Exploration Technologies (OMET) sponsored project, the Ontario Geological Survey (OGS) and the Geological Survey of Canada (GSC) have carried out soil sampling on 2 exploration grids on the Cross Lake Property east of Timmins, Ontario. The purpose of the work is to test, in an exploration setting, soil sampling methodologies developed as part of "Deep Penetrating Geochemistry - Phase II" (DPG), an earlier project jointly funded by the OGS and the Canadian Association of Mining Industry Research Organizations (CAMIRO). The results of the grid sampling and the earlier work are also being used to establish protocols for the use of selective leach geochemistry in the thick and highly variable overburden terrain of the Abitibi clay belt. This paper describes the background, methodologies, field work and initial results of the project. Final results will be available in the spring of 2004 as an OGS publication that will also constitute the OMET final report.

OVERVIEW OF FIELD PROGRAM

The Cross Lake property is located in Sheraton Township on the eastern flank of the Kettle Lakes Esker (Figure 22.1). The property is held by Cross Lake Minerals Limited and hosts a zinc-lead-copper volcanogenic massive sulphide (VMS) deposit with local zinc grades of up to 26% Zn. The property is large and parts of its 10 to 15 km^2 are unexplored. Several of these areas are, or were until recently, optioned by Falconbridge Limited. The program, as it stands, would not be possible without the willing participation of Falconbridge, who provided information on 2 large exploration grids that were used as test areas. The work conducted by Falconbridge includes ground electromagnetic (EM) and magnetic (mag) surveys and the drilling of a number of holes to test targets on the grids. The geophysical and geographic data were freely provided to this project, but the results of test-hole drilling were withheld at our request. This supplied us with 2 large and several smaller geophysical exploration targets that were "blind" with respect to geochemistry or drill control. They are now being evaluated using geochemistry alone with no knowledge of nearby drilling data. Near the end of the project, this geochemical evaluation will be compared with the actual drill results and the reliability of the geochemical assessment will be determined and reported.

Summary of Field Work and Other Activities 2003,
Ontario Geological Survey, Open File Report 6120, p.22-1 to 22-6.

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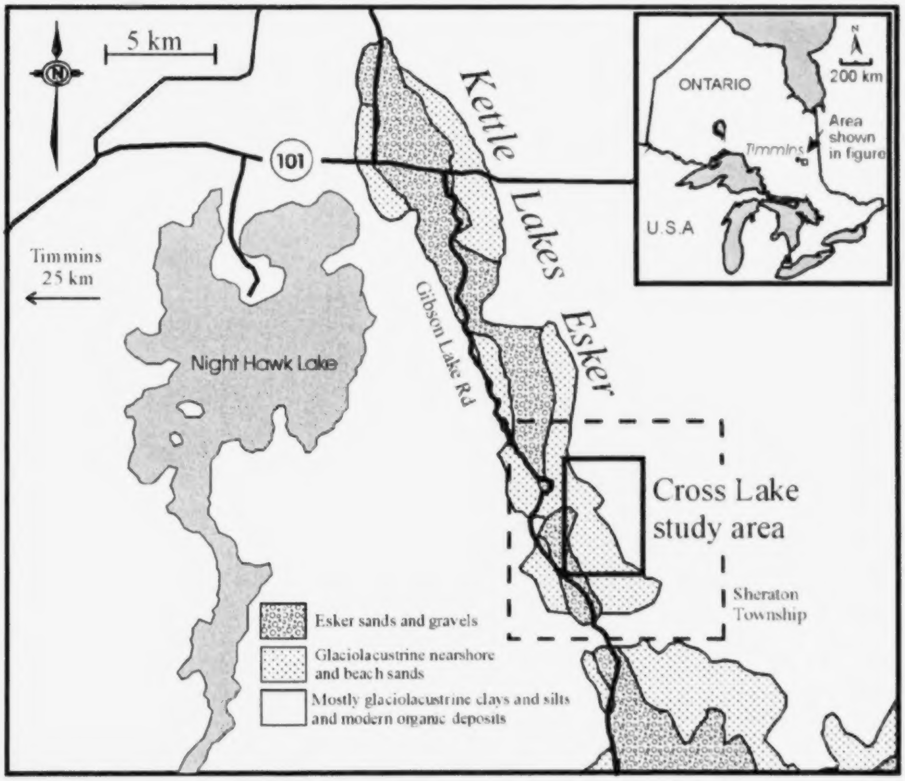
The 2 grids, amounting to approximately 17 line-kilometres (Figure 22.2), were sampled at a 25 m spacing using protocols developed as part of the earlier Phase II DPG program (Cameron et al. in press; Hamilton and Cranston 2001; Hamilton et al. 2002). The methodology section below describes the protocols in 2 parts. The first deals with sampling in dry or seasonally dry mineral soils that have developed at least a partially recognizable soil horizon. This protocol is one of the products of the DPG project. The second protocol deals with organic peat terrain. This protocol was developed using results of orientation field work at the Cross Lake north grid, which is largely overlain by peat, and detailed profiling of peat at the "Marsh Zone", which is a small syenite-hosted gold deposit, located in Hyslop Township east of Matheson, Ontario.

METHODOLOGY

Digital Data Collection

On the 2 grids, a large number of samples were proposed and a large amount of data was to be collected at each site. Therefore, a digital data entry system was warranted. Two sampling crews, consisting of 2 people each, used a weather-proofed palm-sized computer to enter data. A form was set up on the computer, using Pendragon Forms® software, that allowed input of the following site specific information: grid coordinates; date and time; geologist sampler; tree species; moisture conditions; slope conditions; disturbance; and the general ground conditions (e.g., heavily treed, open, etc.). Sample-



N
5 km
101
Kettle Lakes Esker
Timmins 25 km
Night Hawk Lake
Gibson Lake Rd
Cross Lake study area
Sheraton Township
Esker sands and gravels
Glaciolacustrine nearshore and beach sands
Mostly glaciolacustrine clays and silts and modern organic deposits
ONTARIO
200 km
Area shown in figure
Timmins
U.S.A

Figure 22.1. Location of the Cross Lake study area within Ontario and in relation to the Kettle Lakes esker (*from* Hamilton et al. in press).

specific information was collected on up to 4 samples, which included thickness of root mat or sphagnum; thickness of organics penetrated; organic decomposition (where relevant); soil horizon(s) sampled; thickness of Ae soil horizon (if present); sample depth interval; colour; and general comments. Data from each computer were downloaded at the end of every day, which took about 2 minutes, thereby saving about 2 hours of manual data entry. Digital photographs were taken of each site and of the first 20 cm of soil that the auger penetrated.

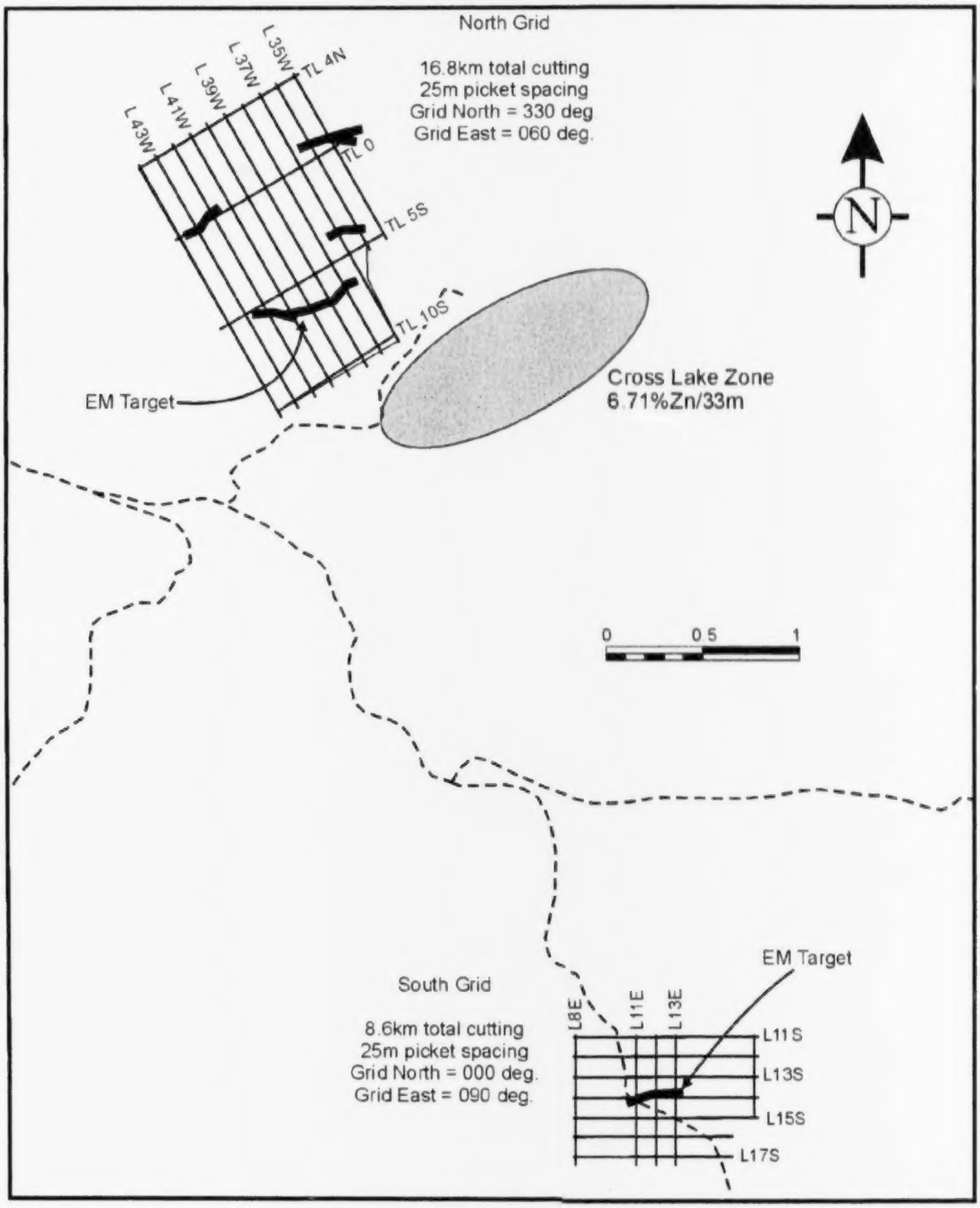

North Grid
16.8km total cutting
25m picket spacing
Grid North = 330 deg
Grid East = 060 deg.
L 35W
L 37W
L 39W
L 41W
L 43W
TL 4N
TL 0
TL 5S
TL 10S
EM Target
Cross Lake Zone
6.71%Zn/33m
N
0
0.5
1
EM Target
South Grid
8.6km total cutting
25m picket spacing
Grid North = 000 deg.
Grid East = 090 deg.
L8E
L11E
L13E
L11S
L13S
L15S
L17S

Figure 22.2. Location of north and south grids on Cross Lake property (Falconbridge Limited, unpublished data, 2002–2003).

Depth-based versus Medium-based Sample Protocol

It was determined during the Phase II DPG project that the depth interval from which a sample is collected is critically important to the success of a selective-leach geochemical exploration program (Cameron et al. in press; Hamilton et al. 2002). An enigmatic "metal accretion horizon" exists at the sites tested that subsequent detailed profiling (Hamilton et al. 2002) has shown to occur in the uppermost 10 cm of mineral soil in areas where the organic soils are 10 cm or less in thickness. This appears to exist regardless of which mineral soil horizon occurs within the 10 to 20 cm depth interval (i.e., Ae or B; Alan Mann, MMI Technology, personal communication, 1999).

In the Abitibi area, where the upper organic soils are greater than 25 cm in thickness, peat usually makes up part or all of the organics. Peat was tested as a sample medium in the Phase II DPG project and the results suggested that a similarly shallow metal accretion zone was likely to exist. In 2002, discrete sampling was carried out in the peat at the Marsh Zone at 10 cm intervals to a depth of 70 cm (Hamilton et al. 2002). An orientation survey was carried out in 2003 on the Cross Lake north grid, which is largely underlain by peat. The results show strong responses in metals and pH over the target features (syenite-hosted gold at Marsh Zone; an unknown EM conductor at Cross Lake) at depths between 10 and 30 cm below ground surface. Depths of less than 10 cm in the peat show very strong accumulations of some metals, especially lead, that would likely overwhelm any subtle signature due to mineralization. These accumulations are diagenetic or anthropogenic or a combination of the 2 and therefore the 10 to 30 cm interval was targeted in the peat sampling.

The results from the Phase II DPG work and the current project show strong background shifts in metal concentration and pH between mineral soil and organic media (i.e., humus or peat). If the sampling protocol were based only on depth, the samples might alternate between organic and inorganic or mixtures of the 2 on any given line. This would cause significant geochemical noise due entirely to variable sample media. Therefore, despite the apparent depth control on the location of the metal accretion horizon, a protocol had to be developed that collected either organic or inorganic media and allowed for their separate treatment during collection, processing and subsequent data analysis. The protocol that was developed involved making a decision based on the nature of the first 30 cm of soil and then using the "dry protocol" or the "peat protocol", as outlined below.

DRY PROTOCOL

At each site, a 7.6 cm (3-inch) diameter soil auger was used to extract the top 30 cm of soil, measured from the base of the leaf litter or top of decomposed sphagnum. If at least 5 cm of mineral soil was present in this zone, the "dry protocol" was used. This consisted of sampling a minimum of 5 and a maximum of 10 cm of the uppermost true mineral soil that contains no significant organic content (i.e., Ae, B or C, but not A_1). A second sample was collected from the shallowest available 5 to 10 cm interval in the overlying organics immediately below the leaf litter. The intended target medium for the mineral soil sample was the Ae (preferably) or the uppermost B-horizon if Ae was not present. Generally, one or the other of these would be developed under the organics where the latter is <25 cm thick; the C-horizon was almost never encountered in such cases during the sampling. The intended target medium for the organics collected over the mineral soil was humus. Peat was rarely encountered where the total organic material was less than 25 cm thick. Samples were stored in twist-top polyethylene bags. At each sample interval, a separate smaller sample was collected for soil pH.

The south grid at Cross Lake is predominantly dry pine forest with only 1 transecting stream valley where moist conditions were likely to be encountered. As a result, the dry protocol was used almost exclusively on this grid. The only exceptions occurred where alluvium was encountered. In these cases, samples of shallow and deep alluvium were collected from the 0 to 10 cm and 10 to 20 cm intervals. On the north grid, the dry protocol was used on approximately 25% of the sample sites.

PEAT PROTOCOL

If, based on the initial auguring, a mineral soil sample could not be collected in the first 25 cm, the organics were almost invariably peat and the "peat protocol" was used. This first required defining ground surface, since there is a certain subjectivity to this in hummocky peat terrain. Hummocks were always avoided and the root mat or sphagnum was peeled back until the living vegetation was removed. In some cases, sphagnum had to be peeled back tens of centimetres until the point where dark brown or black decomposition begins and this was taken as the point from which to measure ground surface.

From the "ground surface" measuring point, the auger was used to penetrate the peat to a full auger-length (approximately 20 cm) and the first peat sample was taken from the *bottom half* of the auger in the interval 10 to 20 cm interval. The auger was then inserted into the same hole and the 20 to 40 cm interval was extracted, from which the top half was sampled, i.e., the 20 to 30 cm interval.

RESULTS

No analytical results are yet available for the main grid sampling. Figure 22.3 shows the orientation survey results for zinc, lead and copper by Enzyme Leach^{SM}. The pH of the leach solution is also shown, which is partly a function of the pH of the sample itself. The data show samples collected in the 1 to 10 cm, 10 to 20 cm and 20 to 30 cm intervals, at 25 m spacing on a transect across the known conductor, the approximate position of which is also shown on Figure 22.3. A multi-parameter anomaly is apparent between 700 and 750 m in the shallower samples (0 to 10 cm and 10 to 20 cm intervals). This is centred about 50 m north of the centre of the conductor. The zinc response is very strong in the shallower samples and coincident with the pH and lead response. The lack of close coincidence with the conductor might be due to zinc mineralization being displaced to the south of the conductive material (sulphide, graphite) or possibly to poor alignment of the geophysical data with the geochemical data in the preliminary work done so far. Copper shows a flat response, but a very strong upward-increasing gradient across the entire transect, possibly due to a diagenetic front.

When the geochemical data for the grid data become available, a geographical information system (GIS) model will be developed, which will include the geophysical data. After these data have been fully assessed, the final stage will be to incorporate the drill hole data, currently held by Falconbridge, and determine how well the geochemical data outlined the actual mineralization. The results of this comparison will be released in the final report in the spring of 2004.

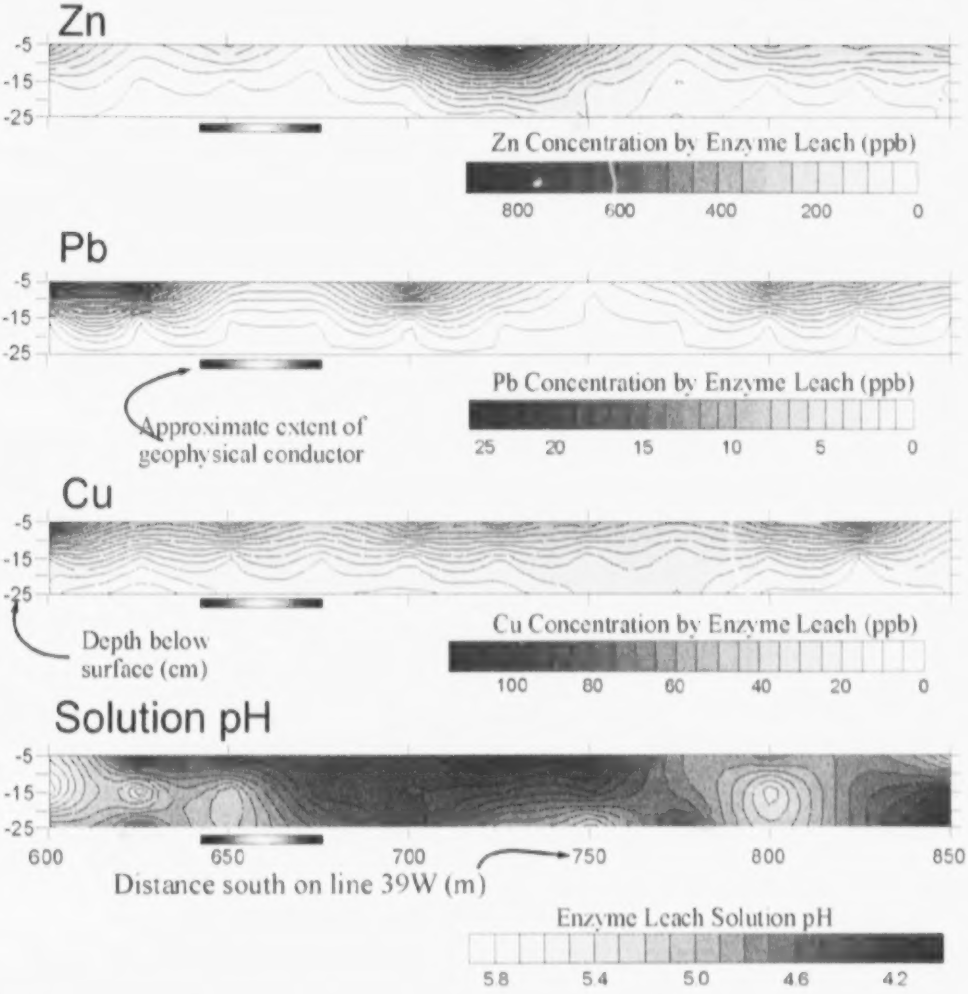


Figure 22.3. Concentration of parameters by Enzyme Leach^{SM} in the upper 30 cm of peat in relation to the geophysical conductor on Line 39 W, Cross Lake north grid. Zinc, lead and pH show a strong response between 700 and 750 m north that does not coincide with the conductor. Since sphalerite is not conductive, this may indicate a zonation in buried sulphides or, alternatively, it may be due to poor control on the position of the geophysical conductor on the grid. This may be clarified when the remainder of the geochemical data become available.

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23. Project Unit 02-019. Groundwater Resource Inventory Papers (GRIPs)

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INTRODUCTION

Under the province's Clean Water Strategy, the Sedimentary Geoscience Section (SGS) of the Ontario Geological Survey (OGS) has established a program of groundwater mapping (Kelly 2002). The major objectives of the program are to delineate and characterize the location of major groundwater aquifers across southern Ontario and in selected areas of northern Ontario. The program will generate information on the physical characteristics of the aquifers and their susceptibility to contamination. The information will be valuable in such initiatives as watershed management, land use planning and source water protection. As well, the data will help support the development of local and regional groundwater resource management strategies.

Currently, a number of projects have been initiated under the groundwater mapping program. These include 1) completion of a GIS-based, "seamless" map of the Quaternary geology for southern Ontario; 2) subsurface three-dimensional mapping of the Waterloo and Oro moraines in southern Ontario; 3) characterization of thin drift cover for nutrient management; 4) data management and modelling for collected groundwater program information and data; and 5) generation of a series of watershed-based groundwater resource inventory papers (or GRIPs). The latter initiative is the subject of this article.

BACKGROUND

As part of an integrated program submission within the 2001–2002 fiscal year, the ministries of Northern Development and Mines (MNDM), Environment (MOE), Natural Resources (MNR) and Agriculture and Food (OMAF) proposed a multi-year strategy to address issues facing drinking water in Ontario. Initial funding was approved for MNDM's "Aquifer Mapping and Susceptibility to Contamination" component of the program in July 2001. For fiscal years 2002–2003 and 2003–2004, additional funding was approved to continue MNDM's groundwater mapping program. This mapping program, delivered through the OGS, contributes to the 4 pillars of the Clean Water Strategy, namely: groundwater information, source protection, managing water taking and reducing risks.

GROUNDWATER RESOURCE INVENTORY PAPERS

In watersheds, groundwater forms an integral component of the hydrological regime. For instance, groundwater provides baseflow to many streams and rivers within a watershed and, thereby, helps to support aquatic ecosystems. In other cases, groundwater may provide an important source of potable drinking water for residential use or may supply critical water supplies for commercial and industrial operations.

Summary of Field Work and Other Activities 2003,
Ontario Geological Survey, Open File Report 6120, p.23-1 to 23-3.

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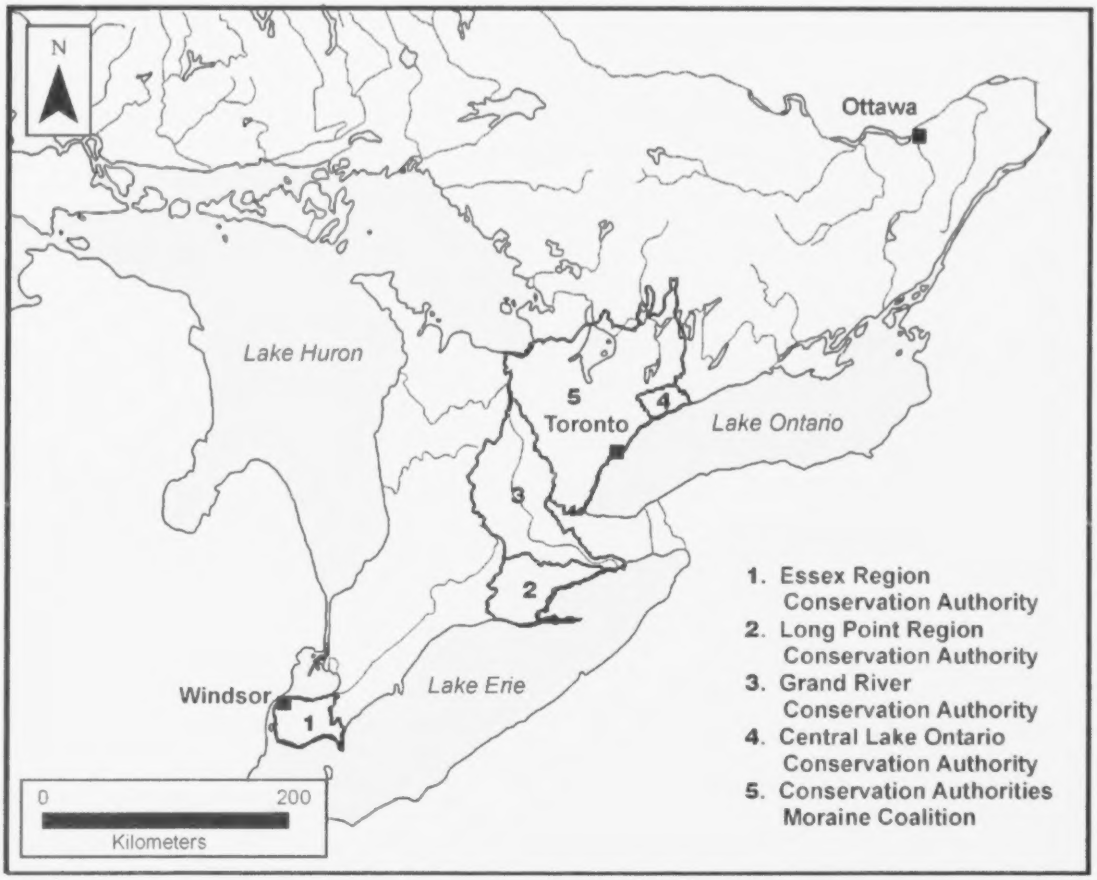
In many parts of Ontario, the availability of fundamental hydrogeological data is insufficient to provide a sound basis for understanding aquifer location, hydraulic conditions, groundwater flowpaths and susceptibility to contamination within watersheds. Basic geologic information, such as bedrock topography, drift thickness, and soil classification, is critical to generating regional conceptual models of the province's groundwater resources.

The OGS has initiated a program to develop a series of watershed-based reports known as Groundwater Resource Inventory Papers (GRIPs). The goal of the program is to generate and distribute a series of regional-scale interpretative maps and reports that can be used to better understand the groundwater systems within individual watersheds. The prototype model for GRIPs is based upon the comprehensive groundwater studies completed by the Grand River Conservation Authority (GRCA) (Holysh, Pitcher and Boyd 2001).

It should be noted that the Ministry of the Environment (MOE) is currently funding a number of municipal groundwater studies throughout Ontario, including the areas covered by GRIPs. The principal objective of the MOE-funded studies is to protect groundwater as a drinking water source. It is, in essence, a wellhead protection strategy.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Windsor
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Lake Erie
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Kilometers
1. Essex Region Conservation Authority
2. Long Point Region Conservation Authority
3. Grand River Conservation Authority
4. Central Lake Ontario Conservation Authority
5. Conservation Authorities Moraine Coalition

Figure 23.1. Location of conservation authorities for which groundwater inventory papers are currently being completed.

The intent of GRIPs is not to replicate the MOE-funded work, but to incorporate the valuable geoscience information collected from these and other projects into a more holistic database. The GRIPs program will provide a series of comprehensive, standardized hydrogeological data and will provide a preliminary evaluation of groundwater systems within the watershed of southern Ontario. It will provide the foundation that will allow the evaluation and comparison of groundwater systems between watersheds. It will also provide the building blocks required to complete subsurface three-dimensional mapping of the province's aquifers.

To date, a series of partnerships have been established with a number of conservation authorities in southern Ontario to complete GRIPs (Figure 23.1). Those conservation authorities include

- Central Lake Ontario
- Grand River
- Essex Region
- Long Point Region
- Conservation Authorities Moraine Coalition (Nottawasaga Valley, Lake Simcoe Region, Kawartha, Otonabee Region, Lower Trent, Ganaraska, Central Lake Ontario, Credit Valley, Toronto Region)

Arrangements and discussions to complete GRIPs with additional conservation authorities are underway. It is hoped that with continued funding the OGS will be able to complete GRIPs for all major watersheds in southern Ontario and selected ones in northern Ontario over the next few years.

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24. Project Unit 02-018. An Update on Three-Dimensional Mapping of Quaternary Deposits in Waterloo Region, Southwestern Ontario

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BACKGROUND

Pressures directed at protecting and preserving the quality and sustainability of groundwater resources within the province have greatly increased over the past decade. Public awareness of these key issues has escalated with the release of the report of the Walkerton Inquiry where the Honourable Dennis R. O'Connor recommended the establishment and implementation of province-wide, watershed-based source protection plans (http://www.attorneygeneral.jus.gov.on.ca/english/about/pubs/walkerton). The O'Connor report clearly states that the public strongly favours source protection over remediation measures as a means of supplying safe, potable drinking water to the residents of the province. The impacts of rapid urban expansion from metropolitan centres and nutrient management practices in rural areas must be addressed when considering the long-term preservation and viability of the provincial groundwater resources.

The cornerstone of source protection lies in geology where a detailed understanding of the properties and three-dimensional architecture of subsurface sediments and rock is essential if well-informed decisions regarding land use and nutrient application in rural areas are to be made. Wise land-use planning, especially within recharge areas, where aquifers are replenished and are most susceptible to contamination, is paramount. The Regional Municipality of Waterloo (RMOW) (Figure 24.1) has taken a proactive approach to source water protection. They strongly supported the development of the *Nutrient Management Act*, an act designed to regulate agricultural practices, such as manure handling, storage and application, and have provided technical input to the province regarding the development of the legislation and the associated standards for implementation (http://www.region.waterloo.on.ca). A monitoring well network unlike any in the province allows the region to constantly monitor and record water levels, water quality and measure aquifer pressures on a regular basis (Robinson 2001). Partnering with the RMOW is the Grand River Conservation Authority (GRCA), which is also very active in both surface and subsurface water monitoring programs. The GRCA has produced a comprehensive technical report on the regional groundwater conditions within the Grand River watershed (Holysh, Pitcher and Boyd 2001). The GRCA approach has been well accepted amongst other conservation authorities and has served as a template on which other studies have been undertaken.

The Regional Municipality of Waterloo (RMOW) is the largest municipal user of groundwater in Canada. Its current daily consumption exceeds 170 million litres, 75% of which is extracted from bedrock and sand and gravel aquifers (http://www.region.waterloo.on.ca). The remaining 25% is obtained from surface water, which is treated and injected back into deep aquifers where it is stored for

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Summary of Field Work and Other Activities 2003,
Ontario Geological Survey, Open File Report 6120, p.24-1 to 24-6.

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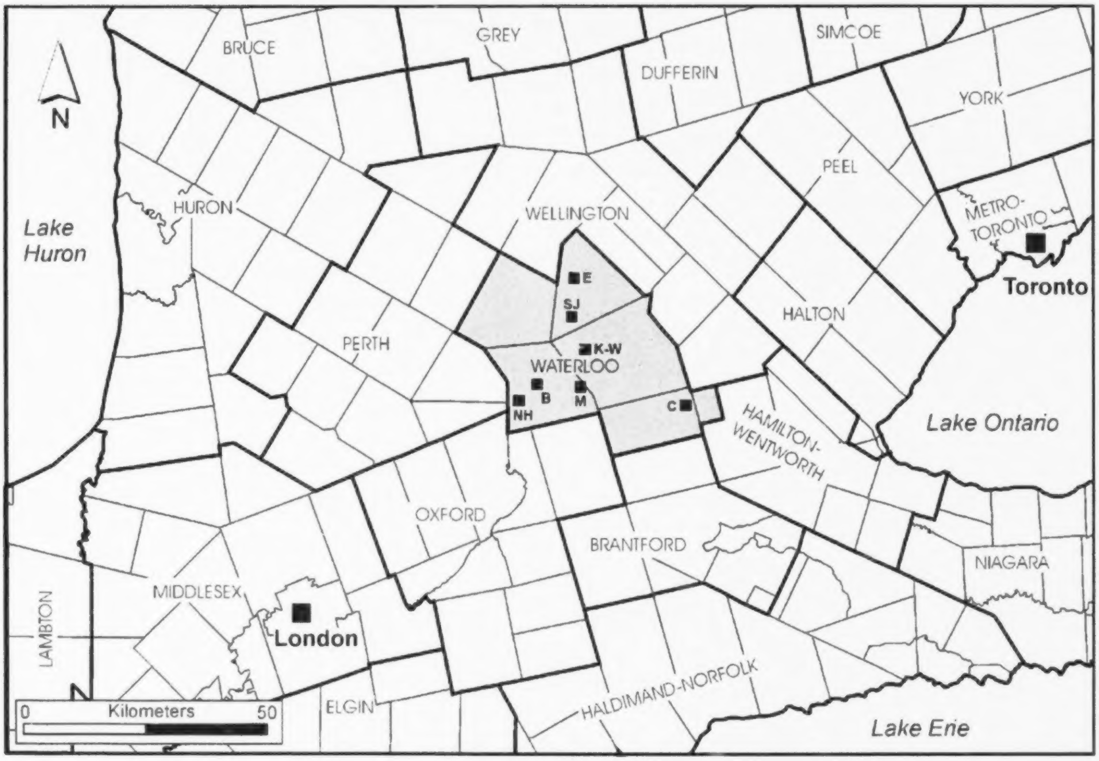
peak consumption periods. The Region's water supply is delivered from a complex network of 67 production wells to approximately 425 000 people living in Cambridge, Kitchener, Waterloo, Elmira, St. Jacobs, Baden and New Hamburg. Seventeen smaller water supply systems provide water to parts of smaller communities within the region.

Since 1991, the region's population has been increasing annually by about 1.5%. The projected population by the year 2016 is expected to top 558 000, an increase of nearly 20% over 25 years (http://www.region.waterloo.on.ca). This dramatic population increase will undoubtedly apply pressure to an already stressed groundwater resource. The region has a Long Term Water Strategy (LTWS) to ensure adequate water supply until the year 2041. Contained within this strategy is a plan to 1) increase the capabilities of the Aquifer Storage and Recovery (ASR) system at Mannheim; 2) increase the number of production wells within the region; and 3) investigate the potential of constructing a water supply pipeline from either Lake Huron or Lake Erie into the region.

AN UPDATE OF CURRENT ACTIVITIES

In an attempt to assist the Region with its Source Protection Plan (SPP) and Long Term Water Strategy, the Ontario Geological Survey has embarked on a project of three-dimensional geologic mapping of the Quaternary sediments that lie within the RMOW. This project is one of several studies currently being undertaken within southern Ontario as part of the Ontario Geological Survey's groundwater mapping program; a provincially mandated directive to study groundwater resources within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SIMCOE
DUFFERIN
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PERTH
K-W
WATERLOO
B
M
NH
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HAMILTON-WENTWORTH
Lake Ontario
OXFORD
BRANTFORD
NIAGARA
MIDDLESEX
LAMBTON
London
HALDIMAND-NORFOLK
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ELGIN
Lake Erie

Figure 24.1. Location of the Regional Municipality of Waterloo in southwestern Ontario (abbreviations: E, Elmira; SJ, St. Jacobs; K-W, Kitchener–Waterloo; NH, New Hamburg; B, Baden; M, Mannheim; C, Cambridge).

the province. The project is currently in its second year and is scheduled to be completed during the 2004–2005 fiscal year. A summary of the main objectives and work plan for this project, including an overview of the current status of geologic knowledge within the RMOW, can be found in Bajc (2002). The current summary provides an update of the work that has been completed at the time of writing as well as a schedule of tasks to be completed over the next fiscal year.

Three main areas of work are currently ongoing as part of the project. These can be summarized as 1) data compilation and standardization; 2) acquisition of new geologic data; and 3) data interpretation, synthesis and presentation. To date, the 3 areas have been paid varying degrees of attention.

Data Compilation and Standardization

Several databases have been created and/or obtained from internal and external sources as part of the data compilation exercise. These databases include 1) borehole logs of monitoring and/or production wells acquired from the Water Services Division of the RMOW; 2) a geotechnical databank originally created by the Geological Survey of Canada (GSC) in the early 1970s and updated and uploaded to an Microsoft® Access database format in the late 1990s by the Department of Environmental Studies at the University of Waterloo; 3) a database of shallow sediment logs captured from hand-written fieldnotes acquired by Dr. P.F. Karrow as part of his Quaternary mapping investigations within the region over the last 4 decades; 4) a similar database of shallow sediment exposure logs acquired by the author as part of field studies during the summers of 2002 and 2003; 5) a high-resolution suite of borehole logs acquired from government reports, theses and unpublished consultants reports housed at the RMOW; and 6) the Ministry of the Environment (MOE) water wells database.

Not surprisingly, most of the databases were structured differently and utilized terminology inconsistent with that proposed for three-dimensional mapping in southern Ontario (van Haaften 2002). A detailed account of the database-building procedures followed can be found in van Haaften, Dodge and Shirota (this volume). Simply stated, terminology in each database was standardized in accordance with material codes developed for the seamless Quaternary geology map of southern Ontario (Ontario Geological Survey 2003). Each unique combination of terms was then translated to populate primary, secondary and teriary material attribute fields. As an example, the MOE water wells database had over 850 unique combinations of materials that required translation. Well-defined rules were used in the translation process. In some cases, judgement by the interpreting geologist was required for the translation. In instances where a translated bedrock unit had overburden materials below, the bedrock unit was reinterpreted and assigned an overburden descriptor. Once the databases were standardized, they were appended and filtered to remove data points with compromised locational attributes. To date, the working copy of the three-dimensional database for Waterloo Region contains in excess of 23 000 data points and 100 000 sediment units. The database will be updated over the next year as new, high-quality records become available.

Acquisition of New Geologic Data

Field activities during the fall of 2002 and summer of 2003 were dedicated primarily to the acquisition of high resolution geophysical data sets. Ground-penetrating radar (GPR) and seismic reflection surveys were undertaken at strategic locations within the RMOW to better understand the three-dimensional geometry and depositional environments of subsurface sediments. Ground-penetrating radar is best suited to areas of dry, granular materials where, under optimal conditions, sounding depths can reach 20 to 25 m. Conversely, seismic reflection is best suited to terrains with fine-grained, water-saturated surface sediments where subsurface structural resolution can reach the metre scale and sounding depths of 100 m are not uncommon.

GROUND-PENETRATING RADAR SURVEYS

Ground-penetrating radar surveys were conducted at 14 sites throughout the RMOW. Most test sites were situated within the Waterloo Moraine. One site was located in the Elmira Moraine at the north end of Woolwich Township and 2 sites were situated over glaciofluvial deposits within the Grand River valley. All GPR lines were surveyed twice using both 50 MHz and 100 MHz transmitters. One short transect line was also surveyed with 200 MHz transmitters. Over 16 km of GPR profiles have been acquired to date. Additional profiling is planned for the fall of 2003. Most of the upcoming surveying will be conducted in sand and gravel pits where calibration of the GPR signature is possible by collecting data at the tops of well-exposed vertical exposures and relating the observed responses to the "unknown" test sites.

The primary objective of the GPR surveying is to determine the depositional environments that comprise the architecture of the Waterloo Moraine. Sites were chosen on the basis of surface morphology and consisted of hummocky terrain, ridges, gently undulating terrain and plains. Areas of hummocky terrain and ridges generally displayed channelized systems of varied scale indicative of deposition in a glaciofluvial and/or subaquatic fan environment. There is very little evidence to support an ice-contact depositional environment. Faults and chaotic bedding are infrequently observed. Reflectors are generally flat lying and commonly truncated along slopes and valley walls. Therefore, much of the apparent hummocky topography is interpreted as erosional in origin. Channelized deposits often lie at the bases of knolls and hummocks indicating incision of pre-existing deposits. In general, gently undulating terrain and plains display variable internal structures. Flat-lying parallel reflectors are interpreted to represent deposition in basinal glaciolacustrine settings. Channelized reflectors on flat plains indicate deposition in shallow braided streams or deltaic environments.

SEISMIC REFLECTION SURVEYS

High-resolution seismic reflection surveys were conducted during the summer of 2003 in collaboration with the Geological Survey of Canada (GSC) as well as by a contractor (Geophysical Applications, GAPS) based out of Guelph, Ontario (Photo 24.1). Both surveys employed the common midpoint method (CMP), which is an adaptation of methods used by the petroleum industry (Pullan and Hunter 1999). The major difference between the 2 surveys was in the seismic source used. GAPS employed a 12-gauge buffalo gun fired at a metre depth, whereas the GSC used their newly acquired Minivibe: a tractor-mounted vibrator similar to that used in the petroleum industry. The main advantages of using the vibrator is that the energy source is delivered into the ground from the road surface, which can either be paved or gravel. Locates are not required for buried utilities as is the case using the buffalo gun. The Minivibe is also capable of being switched over into shear wave mode. Shear wave surveys have been shown to be effective in terrains where gas occurs at depth and may provide better results in areas where low velocity surface layers exist and the groundwater table is at great depth. Tests will be conducted during the fall of 2003 to evaluate the unit in shear wave mode.

In order to determine the best locations for CMP profiling, GAPS undertook a series of 48 channel refraction profiles throughout the region. Receivers were spaced at 4 m and shots were fired at the midpoint of each spread as well as at 1.5 and 3.0 m from each end. A total of 19 profiles were collected and evaluated in terms of quality of response, number of reflectors and depth to bedrock. Results tended to be better in areas where fine-textured sediments occur on surface. Some of the test spreads within the Waterloo Moraine proved to yield very poor results due to the presence of a thick, low velocity layer at surface. On the basis of the results of the 19 test spreads, 9 sites were chosen for detailed reflection profiling. Five sites, totalling 4.89 km, were surveyed by GAPS and 6 sites, totalling 7.2 km, were surveyed by the GSC. Approximately 1 km of survey line was duplicated using the buffalo gun and Minivibe to compare and contrast the responses obtained.

As a follow-up to the seismic reflection survey, the GSC will be conducting downhole velocity seismic profiling in boreholes drilled at strategic positions along the seismic lines. The velocity seismic profiles will allow for calibration of the profiles enabling depth corrections to be made. The profiles will also assist with current research by the GSC directed at relating porosity of water-saturated aquifers to their inherent velocity characteristics.

OVERBURDEN DRILLING

A program of overburden drilling will be undertaken during the fall of 2003. Boreholes will be sited at strategic locations along seismic reflection profiles as well as in areas lacking high-quality subsurface information. Coring will be undertaken using a Christensen PQ wireline mud rotary coring system. Two and a half inch diameter threaded, flush-joint PVC piping capped at the end will be inserted down each hole prior to removal of the drill casing and sealing of the hole with bentonite grout. Downhole geophysical logging will be undertaken at a later date. Monitoring wells may be installed at borehole locations mutually agreed upon by the RMOW and the GRCA.

Photo 24.1. A Minivibe seismic profiling survey in Wellesley Township conducted by the GSC.

OTHER ACTIVITIES

In addition to the activities highlighted above, the OGS is working co-operatively with the Canadian Centre for Remote Sensing (CCRS) on the application of remotely sensed imagery for groundwater studies in the RMOW. To date, Landsat TM and Radarsat imagery has been acquired for the region. It is hoped that the Radarsat imagery will assist with the delineation of recharge areas on the Waterloo Moraine. Fine-grained sediments cap the moraine sands and gravels in places preventing the rapid infiltration of rainfall. Radar imagery can pick up these differences in surface moisture, especially during the early spring when foliage is at a minimum and contrasts in surface moisture is at a maximum. By mapping these differences in surface moisture, one should be able to produce a refined map of confined and unconfined conditions over the moraine.

The RMOW, GRCA and OGS are co-operatively funding a project to update the borehole geophysical database for the Region of Waterloo so that it is compatible with Viewlog®. Following the update, there should be in excess of 450 boreholes with downhole geophysical logs. These logs are invaluable for inferring geologic contacts in boreholes where continuous core was not obtained.

Data Interpretation, Synthesis and Presentation

Data interpretation and synthesis is a labour intensive, iterative process that will require the use of high-powered GIS tools and three-dimensional viewing software. To date, a number of software programs have been utilized in the interpretation and synthesis process. The three-dimensional data is housed in a Microsoft® Access database where it can be easily queried and updated. Preliminary interpretations of the data have been undertaken using ESRI products, such as ArcGIS® and ArcScene®, Viewlog® and GoCAD®. Viewlog® will be used to pick formation tops and to generate cross-sections and surfaces. A suite of derivative and value-added products will be developed following a consultative process with our client groups.

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25. Project Unit 03-021. Subsurface Mapping of the Barrie Area, Central Ontario

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INTRODUCTION

Groundwater is an essential source of drinking water for almost 3 million residents of Ontario (Ministry of the Environment 2001). Over 200 communities within the province use groundwater-based sources that provide drinking water to residential users and that service the industrial, commercial and institutional sectors (Ministry of the Environment 2001). For example, the City of Barrie relies exclusively on groundwater, as it obtains its drinking water from 12 wells that have been drilled into 3 lower aquifers in the central area of the City (Wice 2003). In addition, approximately 90% of rural populations in Ontario rely on groundwater resources for drinking and other uses (Ministry of the Environment 2001).

In areas of rapid urban expansion, such as Barrie, one of Ontario's fastest growing cities (Ministry of the Environment 1998), thorough land use planning strategies must be implemented to ensure that adequate supplies of groundwater exist for future use. As the demand for water will undoubtedly increase with growing population and industrialization, it is vital to protect areas of recharge, where aquifers are replenished, and to locate potential new aquifers. In order to ensure that sound land use planning strategies and effective groundwater protection policies are implemented, a thorough understanding of Quaternary sediments within the area is essential, as these deposits form significant areas of recharge, contain both local and regional aquitards, and include numerous producing aquifers.

In response to increasing rates of urbanization and industrialization of rural areas and the foreseeable pressures that this will have on existing groundwater supplies, the Sedimentary Geoscience Section (SGS) of the Ontario Geological Survey (OGS) has introduced a groundwater program as part of its mandate. This program is aimed at studying groundwater resources within the province by addressing key issues, such as resource location, volume and aquifer susceptibility to contamination. In addition, readily usable data and expertise on surficial materials and bedrock will be available to assist municipal-based groundwater studies. This article briefly summarizes the current status of aquifer mapping studies within the Barrie area (Figure 25.1). This project is being conducted in concert with the University of Waterloo.

OBJECTIVES OF STUDY

The objectives of this study are multifold. The first stage is to construct a three-dimensional geologic model of Quaternary sediments in the Barrie area (*see* Figure 25.1). This model will be used to assist hydrological modelling by delineating potential aquifers and aquitards on both a local and regional scale. Within the study area, a very important landform exists: the Bass Lake kame moraine (BLKM). As very little information on the origin and the internal structure of the moraine is known, it is necessary to undertake a detailed sedimentological study to determine the internal characteristics of this landform,

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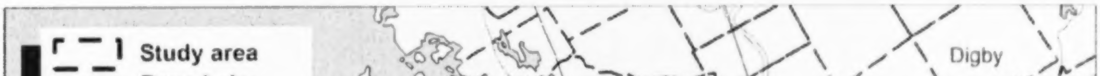
which is the region's largest aquifer. A further aspect of this study is to determine the extent of pre-Late Wisconsinan and Late Wisconsinan deposits in this area.

Construction of the three-dimensional geologic model will follow a standard basin analysis approach (cf. Miall 1999), similar to that adopted by Sharpe et al. (2002) for the Oak Ridges moraine and by Bajc (2002) for the Waterloo moraine. Initial work will involve the compilation and examination of existing data sets that contain subsurface geological information. For the most part, these data sets include archival borehole records held by private consultants, and municipal, provincial and federal governments. In addition, the Ministry of Environment (MOE) water well database will be used to construct bedrock topography and drift thickness maps of the area. The information gathered from these data sets and/or databases will then be used to form the basis of the three-dimensional geologic model.

In areas where subsurface data are scarce, additional geological information will be gathered using surface and downhole geophysical surveys (ground-penetrating radar and shallow seismic reflection). In addition, new stratigraphic boreholes will be drilled to supplement existing geological data. This is necessary for the interpretation of geologically complex areas and will provide control points with which to reference MOE water well data.

REGIONAL GEOLOGICAL SETTING

A generalized description of the bedrock and Quaternary geology of the study area is provided below. For more detailed information, see Liberty (1969), Sanford and Baer (1981), Karrow (1989), Johnson et al. (1992) and Barnett (1992).



Study area
Bass Lake Kame moraine
Lakes
Townships
Roads
Matchedash
Digby
Dalton
Layton
Orillia
Rama
Carden
Tiny
Coldwater
Tay
Mara
Medonte
Georgian Bay
Craighurst
Eldon
Flos
Oro
Lake Simcoe
St. Vincent
Collingwood
Vespra
Barrie
Nottawasaga
Brock
Euphrasia
Sunnidale
Georgina
Innisfil
Tosorontio
Essa
Uxbridge
Scugog
Osprey
East Gwillimbury
0
10
20 km
Mulmur
West Gwillimbury
Melancthon

Figure 25.1. Location map of the Bass Lake kame moraine and proposed study area boundary.

Bedrock Geology

Outliers of Precambrian bedrock are present only in the northern part of the study area. In the townships of Orillia and Medonte, numerous outcrops consisting of granite, gneiss and migmatite are present (Liberty 1969; Sanford and Baer 1981). According to Chapman and Putnam (1984), outcrops of Precambrian metavolcanic rocks also occur at surface in this area.

At surface, Proterozoic rocks of the Grenville Province are separated from the main body of Paleozoic rocks by the Black River Escarpment. This structure can be traced from Uhthoff, westward through Foxmead to Fesserton (Liberty 1969). South of the escarpment, younger Paleozoic (Middle Ordovician) rocks of the Simcoe Group unconformably overlie Precambrian rocks. These include the Shadow Lake, Gull River, Bobcaygeon and Verulam formations (Johnson et al. 1992).

The Shadow Lake Formation has been referred to as part of the "Basal Group" by Liberty (1969), as it forms the uppermost unit of a group of sandstones and arkoses that unconformably overlie Precambrian rocks of the Laurentian Shield. The formation is characterized by greenish grey, coarse-grained sandstones (calcareous arkoses), that are overlain by red and green arenaceous mudstones. The Shadow Lake Formation is overlain by the Gull River, Bobcaygeon and Verulam formations. These formations are collectively referred to as the Simcoe Group. They are predominantly composed of argillaceous and sublithographic, or lithographic limestone and calcarenite with minor mudstone and claystone (Liberty 1969).

Quaternary Geology

Glacial deposits in the study area were most likely deposited from the Lake Simcoe or Northern lobe(s) (Deane 1950; Gravenor 1957) during or after the Port Bruce Stade. However, pre-Late Wisconsinan deposits may exist at depth (Barnett 1991). In general, glacial ice movement across the study area was in a south-southwesterly direction, as is indicated by glacial striae and the orientation of drumlins and drumlinoid ridges (Finamore and Bajc 1984; Barnett 1997).

Despite previous analyses in the Lake Simcoe region, the chronology of glacial events during the Port Bruce Stade of the Late Wisconsinan Substage is not well established and remains poorly understood. This is due to a fragmented and complex deglacial history of the Laurentide Ice Sheet and a paucity of suitable study sites. As such, the following section briefly describes the glacial chronology of the region beginning at the Mackinaw Interstade.

The Lake Simcoe area is known to have been ice covered up to the time of the Mackinaw Interstade of the Late Wisconsinan Substage, at approximately 13 300 years BP (Dreimanis 1977). During this interstade, the Laurentide Ice Sheet, also referred to as the "Northern Ice Sheet" by Deane (1950), retreated to a point north of the study area. According to Deane (1950), a subsequent readvance occurred covering the region with ice during the Port Huron Stade at approximately 13 000 years BP (Dreimanis 1977). Ice retreat dominated again during the Two Creeks Interstade at approximately 12 500 BP (Dreimanis 1977). A short readvance of the Lake Simcoe lobe took place during the equivalent of the "Greatlakean" readvance of the Michigan lobe, at approximately 11 800 years BP (Dreimanis 1977). According to Deane (1950), this readvance of the Lake Simcoe lobe was responsible for the deposition of the Bass Lake kame moraine (BLKM).

At surface, 4 distinct till formations have been identified in the study area. In order of oldest to youngest, these formations are represented by the Bogarttown Till (Gwyn 1972), an unnamed sandy till (Barnett 1992, 1997), the Newmarket Till (Gwyn 1972) and the Kettleby Till (Gwyn 1972). The Bogarttown Till is a stony sandy silt to silt till most likely deposited during the Port Bruce Stade by a southerly advance of the Simcoe lobe (Gwyn 1972). Surface exposures of Bogarttown Till are rare in the study area, occurring at only 5 localities. The Bogarttown Till is overlain by an unnamed stony sand till that is assumed to have been deposited by the Simcoe lobe during the Port Bruce Stade, which in turn is overlain by the Newmarket Till. The Newmarket Till is characterized by a calcareous silt to sandy silt till deposited by the Simcoe lobe during the latter part of the Port Bruce Stade (Gwyn 1972; Barnett 1992). The youngest till in the area is the Kettleby Till. This highly calcareous silty clay to clay till represents a southerly advance of the Simcoe lobe to the Oak Ridges moraine during the Port Huron Stade (Gwyn 1972).

The presence of strata associated with glacial Lake Algonquin, which formed after ice withdrawal from the region, is well documented in the study area (Finamore 1981; Finamore and Bajc 1984; Barnett 1986, 1988, 1989, 1997). Shoreline features relating to the main level of glacial Lake Algonquin and its successors are abundant. In addition, shoreline features found above the main level of glacial Lake Algonquin, possibly related to early glacial Lake Algonquin or glacial Lake Schomberg, have been reported in the area (Finamore 1981; Finamore and Bajc 1984; Chapman and Putnam 1984; Barnett 1997).

The most recent development in the Quaternary history of the area relates to the origin of large "U"-shaped valleys that occur within the study area (Barnett 1989, 1990). It is generally accepted that these steep-walled valleys represent a system of tunnel valleys, also referred to as tunnel-channels (Brennard and Shaw 1994), carved by the rapid release of ponded subglacial meltwater. Although doubtful, these channels could also be related to subaerial incision prior to the last glacial advance (Barnett 1989).

Bass Lake Kame Moraine

The Bass Lake kame moraine (BLKM; Deane 1950), or the Oro moraine (also referred to as the Oro sandhills; Chapman and Putnam 1984), is the most prominent glacial feature in the study area. It covers approximately 165 km^2 (Deane 1950; Finamore and Bajc 1984; Barnett 1988), extending from Bass Lake westward to the eastern edge of Highway 400, west of Craighurst (*see* Figure 25.1). Morphologically, this moraine is best described as a hummocky to rolling tract of land with highly variable relief, from 201 to 396 m asl.

Interpretations of the origin of the BLKM vary. Deane (1950) considered it to be an end moraine, formed during a stillstand of the Lake Simcoe ice lobe. According to Deane (1950), the sediment that formed the moraine was deposited by ice that rested on the northern side of the moraine only. Deane (1950) called for a further ice-marginal readvance into the Lake Simcoe region during what was termed the Lake Simcoe moraine stage, to explain its geometry. He suggested that during this readvance the ice front advanced to, but did not override, the BLKM. Contrary to Deane (1950), Gravenor (1957) suggested that the BLKM is an interlobate formation that has been overridden by ice from the Lake Simcoe basin. Studies by Terasmae (1980) and Chapman and Putnam (1984) concluded that the moraine formed between 2 ice lobes, thereby supporting Gravenor's (1957) interlobate theory. An alternate theory proposed by Chapman and Putnam (1984) suggests that the BLKM is a remnant deposit of an earlier sandy moraine built by the Georgian Bay lobe that was subsequently overridden from the northeast by the last advance of the glacier. More recently, investigations by Barnett (1986, 1988, 1989) support an interlobate origin with the main sediment supply from the ice on the southern side.

RECENT DEVELOPMENTS ON THE BASS LAKE KAME MORAINE

Sedimentological analyses of the BLKM during the summer months of 2003 support a subaqueous outwash fan origin for the moraine (Barnett 1986, 1988, 1989). However, evidence to support deposition within an interlobate setting as envisioned by Barnett (1986, 1988, 1989) was not observed by the author.

Paleocurrent measurements taken from a variety of depositional elements, ranging in scale from bedforms to macroforms (bars) and the attitude of boundary surfaces (surfaces that separate dissimilar lithotypes) indicate a dominant south to southwest paleoflow direction. These measurements are consistent with the last regional direction of ice flow in the area and support a Lake Simcoe source lobe for the moraine. If the BLKM represents an interlobate feature formed by sediment input from ice on both its northern and southern sides (Gravenor 1957; Chapman and Putnam 1984; Terasmae 1980; Barnett 1986, 1988, 1989) northward-trending paleocurrent directions and boundary surfaces should be apparent. Such a trend was not observed during field work.

Preliminary observations suggest that the BLKM is composed of 3(?) stacked subaqueous fan sequences. An alternate interpretation is that the moraine represents a single subaqueous fan consisting of several extensive lobes. However, based on the overall morphology of the moraine, the position of ice-contact slopes (Finamore and Bajc 1984; Barnett 1997) and detailed sedimentological analyses (described below), the former is preferred.

Sedimentology of the Bass Lake Kame Moraine

Aside from generalized statements made by Deane (1950), Chapman and Putnam (1984) and Barnett (1986, 1988, 1989) stating that the moraine represents a series of coalescing subaqueous fans composed mainly of sand with lesser amounts of gravel, detailed studies on the moraine are few (Delorme 1987; Beckers 1998; Beckers and Frind 2000).

The subaqueous fan environment associated with the BLKM is extremely variable and exhibits a complex distribution and spatial arrangement of deposits and sedimentary structures. The main autocyclic control that may have caused these variations within the BLKM can be related to slight shifts in the orientation of glacial conduits and the direction from which sediment was introduced into the receiving basin. These factors are thought to be responsible for abrupt facies transitions observed in strata of the BLKM, channel development and depositional lobe development. These changes are, in turn, overprinted by the larger scale allocyclic control of ice-marginal retreat, which has produced a fining-upward trend across the entire deposit.

Using architectural-element analysis, a technique that groups lithotypes into depositional assemblages known as elements (cf. Allen 1983; Miall 1985), 4 main depositional environments and their associated assemblages have been identified for the BLKM. These include proximal fan, proximal to mid-fan, mid- to distal fan (including laterally extensive massive sands and channel-fill sequences) and distal fan assemblages.

Typically, deposits associated with proximal fan environments in the BLKM are characterized by wedge-shaped assemblages of poorly sorted (disorganized), matrix-supported boulder-gravel and gravel. These assemblages reflect deposition from highly concentrated sediment flows within, or near the mouth of a conduit. To a lesser extent, clast-supported, imbricated gravel deposits are also present within this environment. These assemblages are attributed to high-energy deposition in proximal proglacial channels.

Laterally extensive sheet-like deposits of gravel, interbedded with horizontally bedded sand, planar, trough cross-bedded and ripple cross-laminated sand characterize proximal to mid-fan environments of the BLKM. Deposition of these assemblages occurred in proximal inter-channel zones or within very broad channels in mid-fan zones. Conformable, blanket- to sheet-like deposits of climbing ripple cross-laminated sands represent mid- to distal fan environments in the BLKM. Deposition of these assemblages most likely occurred through suspension fallout by rapidly waning, low-density turbidity currents in mid- to distal channel zones or in distal regions adjacent to main channels.

Laterally extensive, sheet-like deposits of massive sands are also common within mid- to distal fan environments. These assemblages are the result of deposition from high-concentration sediment (hyper-concentrated?) sediment flows that passed beyond channel termini or spilled over their banks. Channel elements within mid- to distal fan environments are readily identifiable by their steep-sided, concave-up, scoop-shaped geometries. Fill assemblages within these elements are characterized by massive to weakly laminated sand. In rare cases, sequences are capped by ripple cross-laminated sand. Channel elements and their associated fill sequences are attributed to erosion and progressive infilling by hyper-concentrated density underflows.

Distal and lateral subaqueous fan environments of the BLKM are characterized by sheet-like deposits of thinly bedded to laminated silt and clay. These assemblages were most likely deposited through suspension fallout from a combination of underflow, overflow and interflow currents. In some locations, rippled or normally graded sands are found interbedded with the silt and clay, usually with lenticular bedding.

RECOMMENDATIONS FOR GROUNDWATER EXPLORATION

At a local scale, exploration for groundwater resources in morainic strata of the BLKM should focus on lateral and distal fan assemblages. Within the BLKM, these assemblages include local aquitards composed of fine-grained sand, silt and clay. These aquitards are commonly overlain by coarser grained, more permeable sediments of the mid- to distal subaqueous fan environments. Undulations or depressions within aquitards associated with distal fan assemblages may act as potential storage areas for groundwater.

At a regional scale, exploration for groundwater resources should be focussed on depressions, cavities and channels cut into or through bedrock strata and the upper surfaces of the Newmarket and Bogarttown tills. These areas represent potential storage areas were groundwater resources would be directed. Although considered to be a regional aquitard by Sharpe, Russell and Logan (2002), it is unlikely that the Newmarket Till underlies proximal- and proximal to mid-fan assemblages of the BLKM. It is probable that the high-energy emplacement of these assemblages partially or completely eroded the Newmarket Till. In these areas, groundwater would percolate to depth until it reached the Bogarttown Till, another substantial aquitard located in the region. In addition, tunnel channels located at the peripheries and perhaps under(?) the BLKM may act as potential pathways and storage areas for groundwater. These areas should be carefully considered when accessing regional groundwater supplies.

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26. Project Unit 03-025. Nutrient Management Project: Characterization of Thin Drift Cover over Various Paleozoic Bedrock Formations in Southern Ontario

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INTRODUCTION

The *Nutrient Management Act 2002*, S.O. 2002, enacted June 2002, is governed by the Ontario Ministry of Agriculture (OMAF) and the Ministry of the Environment (MOE). The Act is designed to protect Ontario's soil and water quality in rural communities by providing guidelines for application of agricultural (i.e., manure) and non-agricultural source material (i.e., sewage biosolids, pulp and paper biosolids) to soils. Since the bedrock situated beneath southern Ontario's farmland may be fractured, consideration must be given to the depth and type of overburden over bedrock. In those agricultural areas covered by thick overburden, the overburden acts as a buffer zone to downward migrating surface waters, effectively filtering contaminants. However, in areas of thin cover (<1.5 m), there may be insufficient overburden to provide the same degree of protection, hence the possibility of movement of contaminants through any bedrock fractures into the groundwater (Nutrient Management Protocol 2002).

Under Part 9 of the Nutrient Management Protocols, application of non-agricultural source material is prohibited on soils that are less than 1.5 m to bedrock. However, application of agricultural source material is allowed and is subject to the same limitations given in the regulation for deeper overburden. Therefore, the development of further guidelines is required to regulate application of agricultural source materials over these thinner drift areas.

As an initial step in developing these guidelines, the geographical identification of areas of thin drift in southern Ontario was completed (OGS 2000). This was followed by the initiation of a field study having the objectives of 1) characterization of key physical properties of thin drift cover (field-saturated hydraulic conductivity, bulk density and particle size); and 2) characterization of any surface joints or fractures within the underlying Paleozoic bedrock formations.

Regions of thin drift cover were identified using the seamless digital compilation of Quaternary geology for southern Ontario (OGS 2003). These areas were either mapped as 1) bedrock exposed at the surface; or 2) bedrock covered by a discontinuous, thin drift layer (Barnett, Cowan and Henry 1991). Map layers, at a scale of 1:50 000, and consisting of bedrock geology, Quaternary geology and soil survey data, were then compiled for these areas. Three primary locations of interest were identified: the Bruce Peninsula, Orillia–Fenelon Falls and Prince Edward County areas (Figure 26.1).

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LOCATION DESCRIPTIONS

Bruce Peninsula

The Bruce Peninsula study area (*see* Figure 26.1), covered by National Topographic System (NTS) map sheets 41 H/4, 41 H/3, 41 A/14, 41 A/15, 41 A/10 and 41 A/11, contains the Breypen land type as the dominant soil classification. The Breypen land type does not contain one particular soil type, but rather pockets of shallow soil of variable material over Paleozoic bedrock (Hoffman and Richards 1954). Also falling into the shallow soil (<1.5 m to bedrock) category in this area are the Wiarton silt and the Wiarton silt loam soils. These soils, however, occur over much smaller areas than the Breypen. The Wiarton series are imperfectly drained, Grey-Brown Luvisols with areas to the west of Owen Sound (*see* Figure 26.1) mapped as 35 to 50 cm to bedrock (Hoffman and Richards 1954).

The most commonly occurring bedrock formations directly underlying each of these soil types are the Guelph, Amabel, Fossil Hill and Manitoulin formations. In the Bruce Peninsula study area, karst features were well developed on many exposed bedrock surfaces (Armstrong and Dubord 1992). The topography in Bruce Peninsula area ranges from undulating to steeply hilly (Gillespie and Richards 1954).

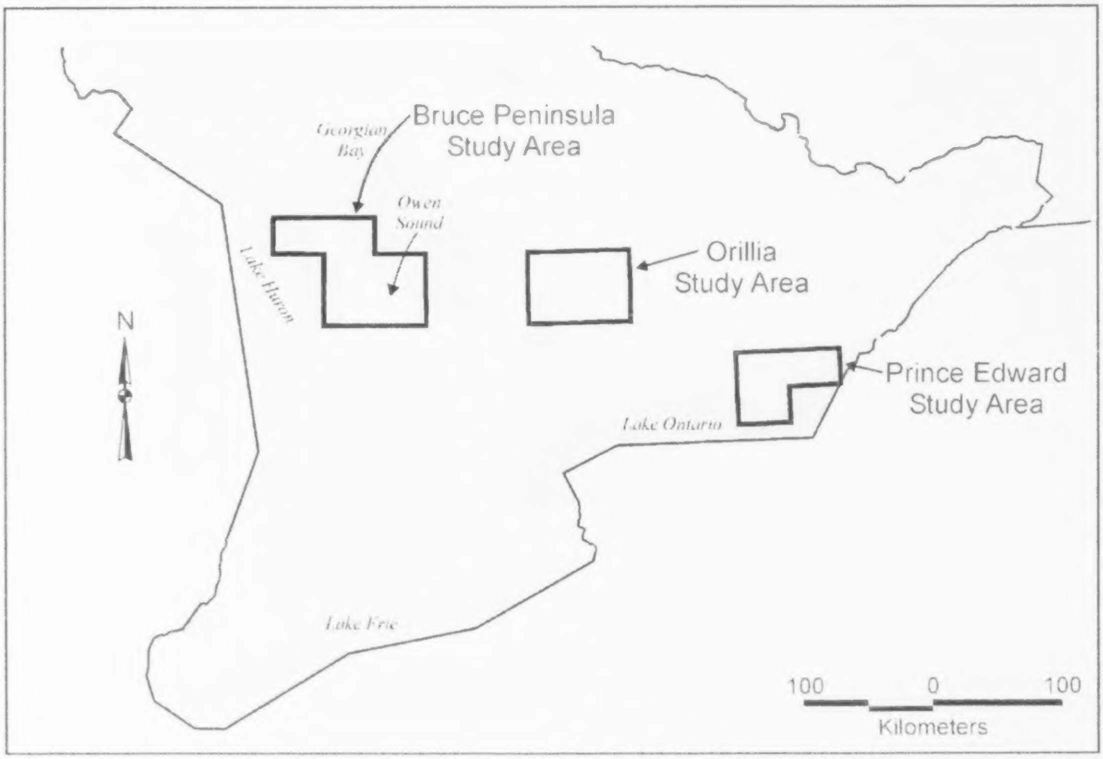
Georgian Bay
Bruce Peninsula Study Area
Owen Sound
Lake Huron
N
Orillia Study Area
Prince Edward Study Area
Lake Ontario
Lake Erie
100
0
100
Kilometers

Figure 26.1 Location of study areas.

LOCATION DESCRIPTIONS

Bruce Peninsula

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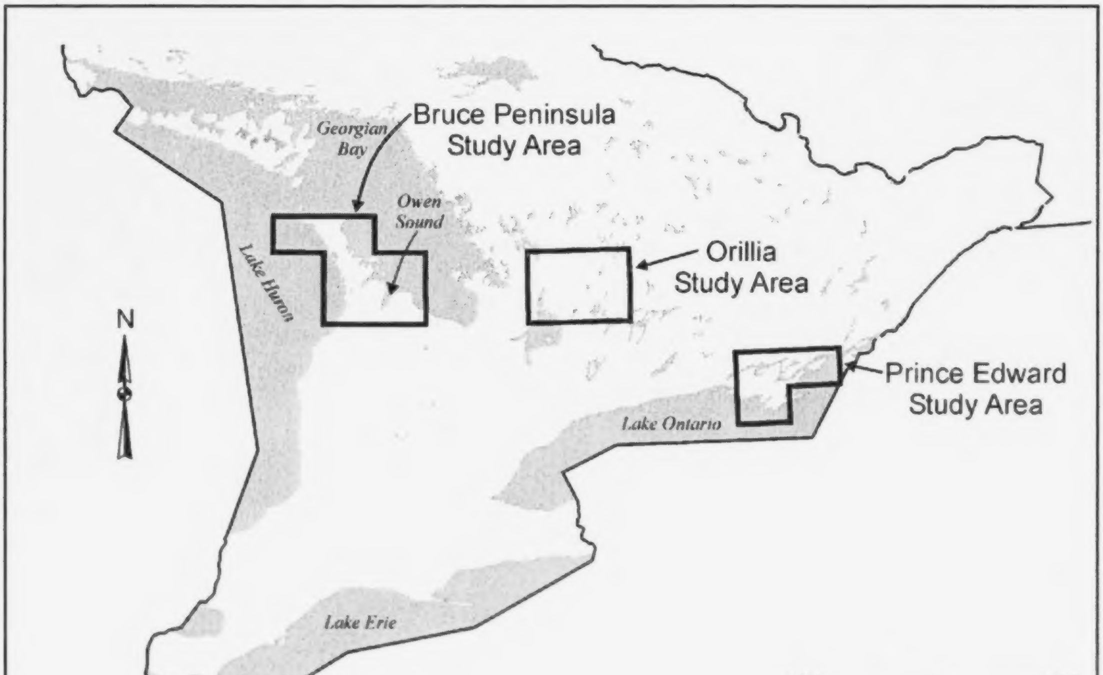
Georgian Bay
Bruce Peninsula Study Area
Owen Sound
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Orillia Study Area
Prince Edward Study Area
Lake Ontario
Lake Erie
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Kilometers

Figure 26.1 Location of study areas.

Orillia–Fenelon Falls

The Orillia study area (*see* Figure 26.1) is covered by NTS map sheets 31 D/10, 31 D/11, 31 D/14 and 31 D/15. The dominant shallow soil types in this region are the Farmington loam and the Dummer loam-shallow phase. The Farmington loam (Melanic Brunisol) typically ranges from several centimetres to a maximum depth of 30 cm of soil over bedrock and occurs as level, broad table lands with occasional rock ledges (Gillespie and Richards 1957). The Dummer loam-shallow phase (Melanic Brunisol) occurs in areas of undulating topography and is mapped as less than 0.3 m to bedrock (Gillespie and Richards 1957). It is very similar to the Farmington with the exception of the occasional occurrence of deep (>0.3 m) pockets of till and a higher percentage of clasts (Gillespie and Richards 1957).

Other shallow soils found in the Orillia study area, but of considerably less extent than the Farmington and Dummer loams, are the Otonobee loam-shallow phase and Emily loam-shallow phase (Gillespie and Richards 1957). The Otonobee loam-shallow phase (Melanic Brunisol) varies in depth from 0.6 to 1.2 m to bedrock and is both internally and externally well drained (Gillespie and Richards 1957). It occurs in topographic regions that are gently to moderately sloping (Gillespie and Richards 1957). The Emily loam-shallow phase is similar to the Otonobee loam-shallow phase with the exception of imperfect drainage. Bedrock generally occurs at a depth of 38 to 61 cm (Gillespie and Richards 1957). Paleozoic bedrock formations most frequently found underlying these soils are the Verulam, Bobcaygeon, and Gull River formations. The general topography of this area ranges from flat to undulating.

Prince Edward County

The Prince Edward County study area (*see* Figure 26.1) is covered by NTS map sheets 30 N/14, 31 C/2 and 31 C/3. As in the Orillia study area, the Farmington loam is the dominant shallow soil type in this region with soil depths no greater than 30 cm. Other shallow soils in this area are the Hillier clay loam and the Ameliasburg clay and clay loam, and to a small extent, the Wapoos, Gerow, and South Bay clay soils. The Hillier clay loam is generally less than 30 cm to bedrock and is well drained. Characteristically, the Hillier contains a high percentage of limestone clasts and has a rolling topography (Richards and Morwick 1948). The Ameliasburg clay and clay loam both typically have thicknesses of 30 cm to 61 cm over bedrock, a high percentage of clasts, and moderately good drainage (Richards and Morwick 1948).

The most commonly occurring bedrock formations underlying the soils in the Prince Edward County study area are the Lindsay, Verulam, Bobcaygeon, and Gull River formations. The topography of the Prince Edward County study area ranges from undulating to moderately hilly.

PROJECT STATUS

The summer of 2003 marked the initial field season for this project. The primary goal of the field study was to characterize the hydraulic conductivity of the overburden in areas of thin drift and assess the degree of jointing in the underlying bedrock. In time, this may allow for the generation of an overall risk assessment.

Field studies were conducted in each of the 3 identified study areas of interest over a 7 week period. Characterization of thin drift over different bedrock formations, where possible, was carried out by the measurement of field-saturated hydraulic conductivity using the Guelph Permeameter method (Reynolds and Elrick 1985), sampling for bulk density and particle size, and collection of detailed horizon descriptions from soil pits. Bulk density sampling protocols were taken from Green (1981) and samples were analyzed for particle size distribution by a laser-based system (Microtrac Full-Range Analyser; Staff of Geoscience Laboratories 2000). The soil pits were dug to reach bedrock and measured 1 m^2 in size. All soils were sampled on undisturbed sites and away from heavily treed areas. Bulk density and particle size samples were taken from the B horizon in soil pits that were texturally uniform. Where there was a change in soil texture, samples were taken from each textural layer. Further field work is currently being undertaken in the 3 study areas to better characterize overburden that ranges from 0.5 to 1.5 m in depth.

Joint characterization from both vertical outcrops and surface pavements were completed for the Paleozoic bedrock underlying the thin drift in each of the study areas. At each outcrop, the following properties were measured using protocols developed by Lapcevic, Novakowski and Sudicky (1999) and Barton (1981). The following measurements and features were noted for each outcrop:

- spacing for sets of joints
- length of joint trace and type of termination (off the outcrop, in rock, or against another joint)
- strike in surface pavement and inferred strike with measured dip in vertical sections
- degree of karsting
- joint aperture
- wall roughness
- type of filling
- degree of seepage

The goal of this project is to ultimately combine the results of the overburden study with the joint characterization of the underlying Paleozoic bedrock and use this data to assist in the development of guidelines for the application of agricultural source materials on areas with overburden of less than 1.5 m.

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27. Project Unit 02-024. Groundwater Geoscience Data Management

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INTRODUCTION

Computer data management is an integral part of most projects carried out by the Sedimentary Geoscience Section (SGS). This article highlights the following data management activities:

- Surficial geology of southern Ontario, a geographic information system (GIS) based map compilation with a database component
- Three-dimensional geology mapping of surficial sediments. These projects are producing three-dimensional geologic models, using computers, of the subsurface geology and aquifers in specific areas of Ontario
- The Sedimentary Geoscience Observations (SGO) database, a data warehouse of surficial geochemistry, indicator mineral data and geological field observations
- Portable computer systems used in field data capture

All of the above projects begin with data modelling. This is followed by methodical project execution, using the Ontario government's Land and Resources Cluster-standard database and GIS software as much as possible. Standard spatial referencing is used; that is, we endeavour to accurately reference all data to the provincial Land Information Ontario (LIO) digital base maps at scales of 1:10 000 (southern Ontario) and 1:20 000 (northern Ontario).

SURFICIAL GEOLOGY OF SOUTHERN ONTARIO

This digital map data product was released in October 2003 as 2 CD-ROMs containing "seamless" surficial geology map data for southern Ontario (Ontario Geological Survey 2003). The released product is a geographic information system (GIS) based map of the surface and near-surface geological materials, mapped at a nominal depth of 1 m. The data are useful for many purposes, including ground and surface water studies, land-use studies, geotechnical investigations and mineral exploration.

A working data model, spatial referencing, standard attributes and feature codes were determined in the fall of 2000. The working data model comprised standard GIS layers, such as geology polygons representing mapped materials; geology lines representing features, such as eskers and beaches; geology points, such as glacial striae; and annotation. The working data model was used in processing and assembling the many individual maps used in the project. It is also used in the published data product.

Summary of Field Work and Other Activities 2003,
Ontario Geological Survey, Open File Report 6120, p.27-1 to 27-6.

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Creating the map included the following steps:

- adjusting scanned raster images of paper maps to the base map, and heads-up (on-screen) digitizing and attribution
- adjusting existing digital maps to the base map, and converting their format and data structure to the project standard
- creating and applying a geological legend translation table to bring all maps under a single provincial legend
- field and office work to correct inconsistencies between individual maps, and performing the required corrections to the digital maps
- assembling the individual maps into a map covering all of southern Ontario, for the published CD-ROM data product

Quality assurance checks were carried out throughout the process. The project used ESRI® ArcGIS® and Microsoft® Access software.

Land Information Ontario (LIO) data analysts worked with SGS staff throughout the project, to ensure that the data can be loaded into the Earth Resources and Mineral Exploration webSites (ERMES), which is hosted within the LIO on-line data warehouse. For this work, the analysts created a logical data model, data import specifications and documentation, so that the data can be brought into LIO in the future.

A more complete description of the "Surficial geology of southern Ontario" may be found in Dodge, Gao and van Haaften (this volume).

THREE-DIMENSIONAL GEOLOGY MAPPING OF THE REGIONAL MUNICIPALITY OF WATERLOO

The Waterloo Region project is described by Bajc (this volume). Slattery (this volume) describes a similar project, which is being carried out on the Oro Moraine near Orillia.

Van Haaften (2002) described a logical data model for three-dimensional geology mapping. In summary, there are data including two-dimensional geology maps and topography maps; vertical cross-sections, such as geophysical profiles; point information databases of borehole information and field mapping observations; and raster data, such as a digital elevation model. From these inputs, surfaces defining the top and bottom of subsurface geological formations and aquifers may be defined. Subsequently, a true three-dimensional computer model of the subsurface geology may be generated.

The data processing work flow used in the Waterloo project is explained below, and it is outlined in Figure 27.1.

Data were collected from various sources. Water well databases included the Ministry of the Environment (MOE) water well records and the Regional Municipality of Waterloo's water well database. Geotechnical borehole data was obtained from the University of Waterloo, however, the database originally came from the Geological Survey of Canada (GSC) (Bélanger 1974). The "field notes" include notes collected during field work by Bajc (2002) and from earlier mapping by Karrow (1987, 1991). Using Microsoft® Access software, technical terms were translated using a series of queries. All records were then appended to standardized tables. A new field was added to the standardized database to keep track of which original database each record came from.

A working copy database was created from the standardized database after applying a "filtering" process. The reliability of each record was assessed based on the accuracy of geographic location, elevation as well as the source of data. All unreliable records were then removed (filtered) from the working copy database. This process was carried out using a series of queries. Creating a multi-query routine facilitates

- keeping clear records of what was done to the data set
- later troubleshooting and modifications to the process
- repeating the process after new records are added

The working copy database is currently being used for manual interpretation of geological formations. This process is carried out using Viewlog® software, in conjunction with borehole data, surficial geology map data and geophysical profiles. Raster surfaces with elevation (or thickness) values are continuously created from this database using such techniques as kriging, in ESRI® Spatial Analyst® software. The generated surfaces are evaluated and used to enhance the quality of the interpretation process. When the interpretation process is complete, the final surfaces will be used to produce three-dimensional models (solids) and two-dimensional maps. The final surfaces will also be used in further processing, such as hydrogeological calculations to predict the movement of groundwater. A preliminary three-dimensional model was prepared in June 2003, in partnership with the Mining Innovation, Rehabilitation and Applied Research Corporation (MIRARCO). This three-dimensional model utilized GoCAD™ software and MIRARCO's virtual reality theatre.

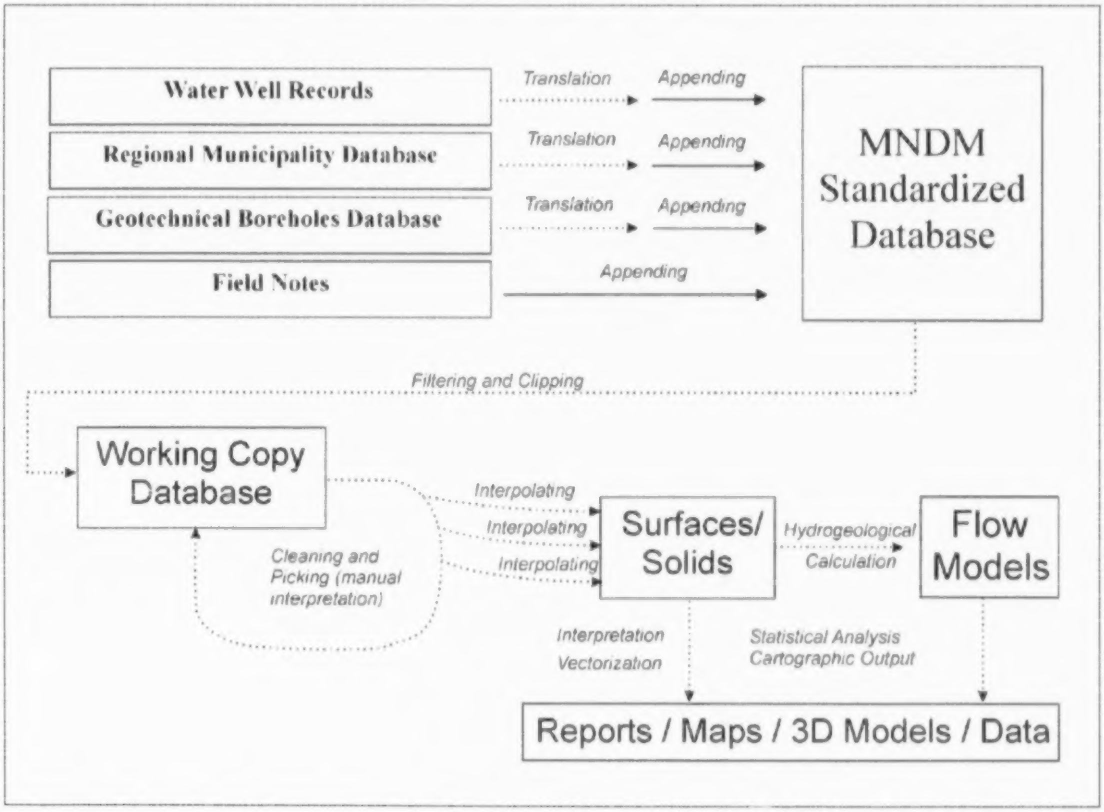
Water Well Records
Regional Municipality Database
Geotechnical Boreholes Database
Field Notes
Translation
Appending
Translation
Appending
Translation
Appending
Appending
MNDM Standardized Database
Filtering and Clipping
Working Copy Database
Interpolating
Interpolating
Interpolating
Cleaning and Picking (manual interpretation)
Surfaces/ Solids
Hydrogeological Calculation
Flow Models
Interpretation
Vectorization
Statistical Analysis
Cartographic Output
Reports / Maps / 3D Models / Data

Figure 27.1. Three-dimensional mapping data processing work flow.

SEDIMENTARY GEOSCIENCE OBSERVATIONS DATABASE

The SGO database project was described earlier by van Haaften, Ernsting and Hoffer (2002). The objective of this project is to create a data warehouse of surficial geochemistry, indicator mineral data and geological field observations. Data include lake water geochemical analyses, and lake sediment, river sediment, glacial till and other sample media analyses.

Data loading by a contractor of existing Miscellaneous Release—Data (MRD) data sets continued in 2003, and the amount of data in MNDM's Oracle® database doubled. By June 2003, the database contained information from 73 MRDs: approximately 60 000 sampling locations, 130 000 samples and 5 000 000 geochemical analyses, plus many mineral grain counts and other data. In September 2003, a still larger Oracle® data set was received from the contractor, representing 79 MRD data sets, all that had been currently published by MNDM. Loading of this final data, and final quality assurance with possible corrections, were planned for completion in 2003.

MNDM worked with the Geological Survey of Canada (GSC), to load data from the SGO database for 6 lake sediment MRDs into an experimental Internet mapping application. This Internet application, with data from across Canada, was demonstrated at the Canadian Geoscience Knowledge Network (CGKN) national meeting in Toronto in March 2003.

Building on the GSC work, MNDM prepared specifications for a possible Internet view of the SGO data, displaying proportional dot maps, and having the capability to inspect and report on detailed information about any sample. MNDM also prepared a very simple data model (Figure 27.2) to support

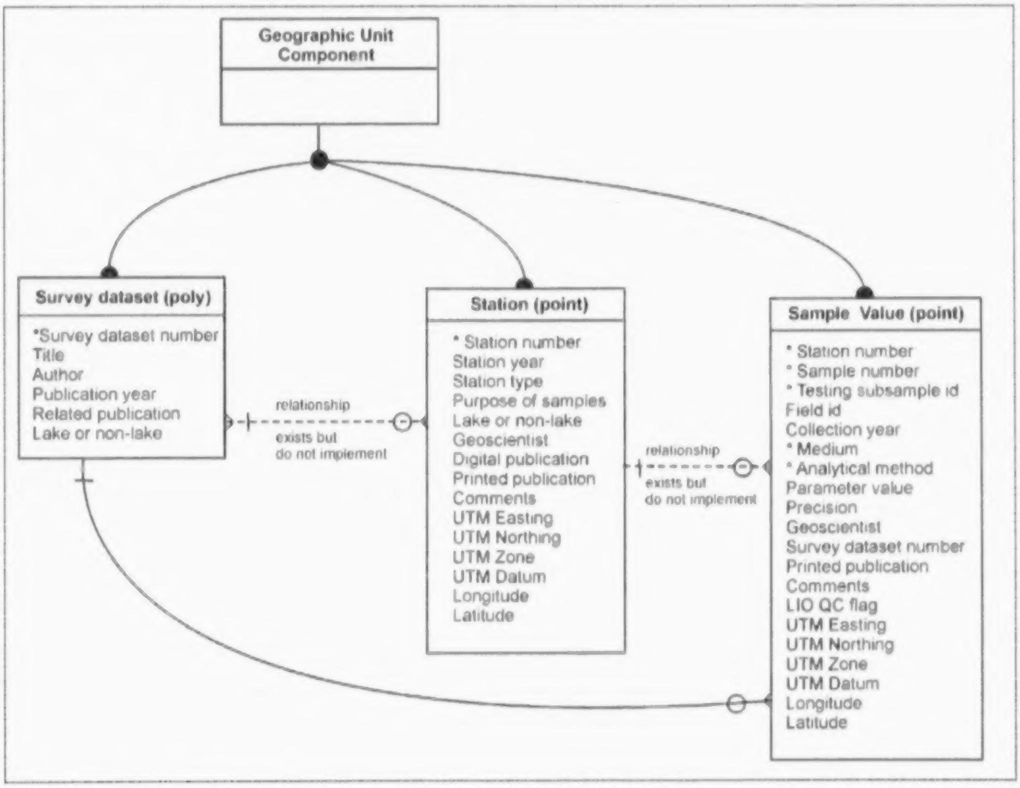
Geographic Unit Component
Survey dataset (poly)
*Survey dataset number
Title
Author
Publication year
Related publication
Lake or non-lake
relationship
exists but do not implement
Station (point)
* Station number
Station year
Station type
Purpose of samples
Lake or non-lake
Geoscientist
Digital publication
Printed publication
Comments
UTM Easting
UTM Northing
UTM Zone
UTM Datum
Longitude
Latitude
relationship
exists but do not implement
Sample Value (point)
* Station number
* Sample number
* Testing subsample id
Field id
Collection year
* Medium
* Analytical method
Parameter value
Precision
Geoscientist
Survey dataset number
Printed publication
Comments
LIO QC flag
UTM Easting
UTM Northing
UTM Zone
UTM Datum
Longitude
Latitude

Figure 27.2. Simplified SGO data model for the Internet and CD-ROM.

the Internet view. In this data model, there are 3 GIS layers: survey data set polygons, station points and sample value points. Each GIS layer has a flat attribute table, for which the fields or attribute columns are shown in the diagram.

LIO will be implementing the SGO database within the ERMES online system. By September 2003, LIO staff had informally indicated that the suggested Internet view and data model are feasible, but details still needed to be worked out.

MNDM will have significant work to convert and standardize data to be usable in the new data model. For example, the Oracle® database may contain values for the same element and analytical method, using different units of measurement, such as parts per million and percent. Such differences must be standardized. Once the data are ready for loading into LIO, then MNDM may also release the data on CD-ROM, for use by clients with desktop GIS software.

FIELD DATA CAPTURE

Sedimentary Geoscience Section projects have used Palm® handheld computers with Pendragon Forms® software for data capture since the 1999 field season (van Haaften 1999). Advantages include

- data is only entered once (never transcribed)
- pick lists ensure consistent data entry
- the hardware and software are inexpensive and quite reliable
- data collection forms are very easy to set up

In the groundwater program, a Palm® handheld computer was used to collect information about soils and bedrock at field study locations for a thin drift characterization project (Strynatka, this volume). Information was collected concerning the study location (station) including bedrock information. Information was also collected for the textural soil layers, joint sets (bedrock fracture sets) and individual bedrock fractures. The data model for the thin drift characterization project is shown in Figure 27.3. Until this year, the most successful Pendragon Forms® databases used by the Sedimentary Geoscience Section had only a single form and table; however, the relatively complex data model for the thin drift characterization project worked well.

In the three-dimensional geology mapping project for the Regional Municipality of Waterloo, Microsoft® Access forms running on a laptop computer were used for data capture in the field. A laptop computer with GIS software was carried in this project, so it made sense to also use Access software.

SUMMARY

This article has shown how data management and data processing are integral to projects of the Sedimentary Geoscience Section. Projects usually begin with planning and data modelling. These tasks are followed by methodical project execution, using the Ontario government's Land and Resources Cluster-standard database and GIS software, where possible and utilizing standard spatial referencing and other standards.

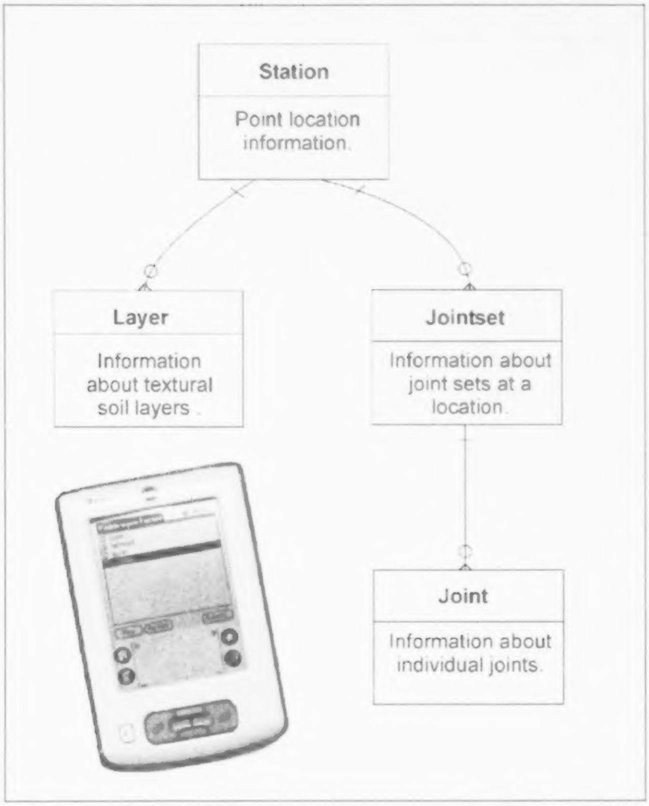
Station
Point location information.
Layer
Information about textural soil layers .
Jointset
Information about joint sets at a location.
Joint
Information about individual joints.

Figure 27.3. Data model for thin drift characterization field work using a Palm® handheld computer.

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28. Project Unit 01-013. Surficial Geology Map of Southern Ontario

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INTRODUCTION

In response to the demand for readily accessible and easily understood information on the surficial sediments of southern Ontario, the Ontario Geological Survey (OGS) has generated a geographic information system (GIS) based, seamless map of the Quaternary geology for the region.

Over the past 40 years, the OGS and Geological Survey of Canada (GSC) have completed Quaternary mapping, primarily at a scale of 1:50 000, for most of southern Ontario. This mapping provides a wealth of information concerning the surficial materials that cover the landscape. Over the years, users of these maps have been many and the uses varied. However, with increased usage of digital mapping software and demand from clients for readily accessible, user friendly, surficial geology maps the existing map tiles were found to have many limitations for use in the digital world. Therefore, it was decided to convert all existing Quaternary geology maps covering southern Ontario into a seamless, attributed GIS-based map that would provide users with a flexible, easily used and understood product. This digital map data product was released in October, 2003, as 2 CD-ROMs containing "seamless" surficial geology map data for southern Ontario (Ontario Geological Survey 2003).

The final product resulting from this project will also form an information layer in the Land Information Ontario (LIO) warehouse. Initial funding for the project was supplied by the Water Resources Inventory Program of the Ministry of the Natural Resources (MNR) and is currently supported by the Ministry of Northern Development and Mines groundwater program.

PROCESS

The first phase of this project, as set out in the initial work plan, was completed in March 2002 (Bajc et al. 2001). The software used to create the seamless Quaternary coverage in a GIS-structured format was ESRI® ArcMap® 8.1 and ArcInfo® Workstation. A total of 124 maps, 36 of which belong to the GSC were used to create the seamless coverage. These original, tiled maps existed as either digital vector or raster format. The raster images were "rubber sheeted" to a geographic base and maps that required vectorization were digitized (heads up) by a contractor according to the project standards. All existing vector maps were brought in line with the Request for Tender (RFT) standards used by the contractor via the Geomatics Service Centre in Peterborough. Once all data was delivered to the Ontario Geological Survey, the following tasks were completed:

- all required edits of attributed vector data from original maps
- standardization of attribute tables

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Ontario Geological Survey, Open File Report 6120, p.28-1 to 28-3.

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- quality control and assurance. All data received from contractors was reviewed to ensure standards set for the project were met
- all coverages were clipped to new neatline which had been created by staff of the Geomatics Service Centre, to ensure smooth migration of tiled sheets to single appended Ontario coverage
- completion of a geological symbols library in ArcMap® 8.1
- creation of an appended coverage for southern Ontario joined to a common legend maintaining a tiled structure for each individual map

The second phase of this project involved the generation of a "seamless map" (Gao, Dodge and MacDonald 2002). Appending 124 maps, each with different authors and different legends, was an arduous and challenging task. All boundary faults existing between individual map sheets were corrected. Corrections were based on geologists' field investigations, review of bedrock geological maps, aggregate resource inventory papers (ARIPs), aerial photographic interpretations, as well as a digital elevation model (DEM) produced by the MNR. The result of phase II is a tiled seamless map of southern Ontario. Map boundaries were maintained through the edge-matching phase. Edits were completed using workstation command line. The OGS felt it was imperative to track all edits made to the original maps during the edge-matching phase. All edits were captured as attributes in both the polygon attribute and arc attribute tables. It was decided that because of file size, editing would be done on the individual zone coverages first. Once each zone was seamless, Universal Transverse Mercator (UTM) zone 18 coverages were projected into zone 17. The final join and boundary fault edits were then completed along the zone boundary.

FINAL PRODUCT

Polygonal, point and line information was captured as part of the automation process. Coverages created include geology polygons (sgu_poly), point information (sgu_point), line information (sgu_line), hummocky topography and moraines (sgu_mor), miscellaneous areas such as dunes (sgu_misc), pits and quarries (ogs_pits) and geological annotation (sgu_anno). Attribute tables contain various geological related information. At present, the map is seamless on 4 attributes: geology, primary material, genesis and formation.

The map data set consists of 7 coverages capturing information on 1) Quaternary geological units; 2) sand and gravel pits; 3) linear features, such as eskers and bluffs; 4) oriented point features, such as drumlins and striae; 5) other polygonal coverages, including hummocky topography and moraines; 6) miscellaneous polygonal coverages, including areas of dunes and 7) geological annotation such as moraine names. Also included is a shaded relief image (in JPEG format) for southern Ontario created using the tiled digital elevation model (DEM) produced by the MNR. Other base information provided in this data set include Natural Resource Values Inventory System (NRVIS) roads, NRVIS lakes and upper tier municipal boundaries. The MNR granted permission to release a "weeded" version of the NRVIS roads coverage. The roads coverage provided in this data set includes only primary roads that have been stripped of all attributes. The MNR also granted permission to release the NRVIS lakes information. The lakes coverage only includes those lakes having an area greater than or equal to one million square metres. The upper tier municipal boundaries information was obtained from The Ministry of Municipal Affairs and Housing (MMAH). This vector coverage does not provide any attribute information.

Other information provided includes a user document that explains the GIS process, a "readme" file, metadata, a font file, a printable version of the map (in PDF format), as well as ArcInfo® interchange files (e00s). Disk 1 contains a complete set of data in geographic projection (decimal degrees, North American Datum 1983 (NAD 83)). Disk 2 contains the same data, but in the Universal Transverse Mercator (UTM) co-ordinate system, NAD 83 datum. Many clients may prefer to use the UTM data because their data may already be in this projection. In UTM, there are zone 17 and zone 18 data sets, representing the west and east portions of the map. UTM data may be processed relatively quickly because they are smaller than the full southern Ontario data set. Data are available in ESRI® ArcGIS® with a completed project file (*.mxd*).

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29. Project Unit 02-025. Grand River Conservation Authority Geology and Applied Water Resources Management

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INTRODUCTION

The Grand River watershed is located in southwestern Ontario 100 km east of Toronto (Figure 29.1). It is home to approximately 800 000 people and drains an area of 6800 km^2, the largest direct drainage basin to Lake Erie on the Canadian side of the border. It is an inland river system. Eighty percent of the watershed's population relies on ground water for their water supply and 75% of the population discharges treated effluent to the river system.

The Grand River Conservation Authority (GRCA) is one of 38 conservation authorities in Ontario. These conservation authorities are tasked with managing the natural resources of the watershed except for minerals and petroleum.

The GRCA covers 38 local municipalities. Representatives from these local municipalities form the GRCA local board. The local board plays a very important role in the business activities of the conservation authority by providing direct accountability to local municipalities and directing the efforts of the conservation authority to relevant local issues. This arrangement is monitored by the other conservation authorities in the province and allows each individual conservation authority to be unique because local issues vary across the province.

In 1996, the GRCA began an update of the Grand River Watershed Management Plan. This plan examined resource management issues at a watershed scale. At the time, working groups were formed to deal with various resource management components including, but not limited to surface water, groundwater, water quality, population growth, fisheries management and natural heritage. A hydrology and groundwater committee was formed to focus on the surface water and groundwater issues throughout the watershed.

The hydrology and groundwater committee is composed of hydrologists, hydrogeologists and water resource engineers from federal, provincial and municipal governments, local universities and private sector consulting. The first task of the committee was to identify key information layers that were needed to update the watershed management plan from a surface water and groundwater perspective. It became apparent at this time that geological information would play an important role in developing a management plan and providing a good technical understanding of water quantity and groundwater movement in the watershed.

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Ontario Geological Survey, Open File Report 6120, p.29-1 to 29-9.

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At the time of the watershed management plan update, most information bases were in paper form only. The committee discussed the need for soils or geology information to form the basis for modelling and development of a conceptual understanding of key watershed processes. Digital soils mapping was not available across the watershed and it was not practical, given time and budget constraints, to create digital soil maps to cover the watershed. It also became apparent that the surface water and hydrology user community tended to rely on soils information, whereas the hydrogeology user community tended to rely on Quaternary geology information. Through discussions, it was decided that having watershed coverage of the Quaternary geology would form a good base from which to conceptually understand the watershed. This information base was also a practical base to convert to digital form and offered the potential to help integrate the surface water and groundwater user community.

DEVELOPMENT OF DIGITAL GEOLOGY COVERAGES

The Ontario Geology Survey (OGS) was approached in 1996 to obtain permission to digitize the Quaternary geology map tiles covering the Grand River watershed. Technical support was also needed from the OGS to match the sheets covering the watershed into a seamless coverage. Co-operatively the GRCA and OGS worked together to create a seamless Quaternary geology coverage across the Grand River watershed. This was the first time a project of this size had been done for southern Ontario, with the involvement of a conservation authority.

In early 1997, the first version of the seamless Quaternary geology map was released and, for the first time, a seamless digital coverage of Quaternary geology was available for the entire watershed (Figure 29.2). Quaternary geology controls or influences several watershed processes. The map immediately advanced the technical understanding of key areas of the watershed and formed the basis from which to develop conceptual models of key watershed processes.

The success of the map was instant. The fisheries management component of the watershed plan utilized the Quaternary geology map as the basis for the fisheries management plan. The watershed was divided into 3 zones: the northern till plain, the central moraines and the southern till plain (*see* Figure 29.2). This base map was used to facilitate input into the fisheries management plan from stakeholders up and down the basin. The Grand River Fisheries Management Plan was a joint initiative between the local Ministry of Natural Resources (MNR) District and the GRCA. It was released in 1998 and received a Provincial Amethyst Award.

In addition to digitizing the Quaternary geology information, the GRCA also digitized information on the areas of moraines or hummocky topography and the bedrock geology. Physiographic features on the moraine areas were digitized to help identify areas in the watershed where disconnected drainage may exist (Figure 29.3). Disconnected drainage is an important process on the landscape that affects both surface water and groundwater. These areas may hold water thereby reducing the amount of surface water runoff and increasing the amount of groundwater recharge. It was found that, in the absence of other information bases, mapping of moraine areas provided a good surrogate to represent this process.

Again, this map became an instant success and resulted in an unprecedented compilation of data for southern Ontario. For the first time, a seamless digital coverage outlining moraine areas was available across an entire watershed.

The examples developed in the Grand River watershed helped raise the profile and highlighted the importance of having high-quality digital Quaternary geology information. The Ontario Geological Survey has now completed digital coverage of the Quaternary geology across southern Ontario (see Dodge, Gao and van Haaften, this volume).

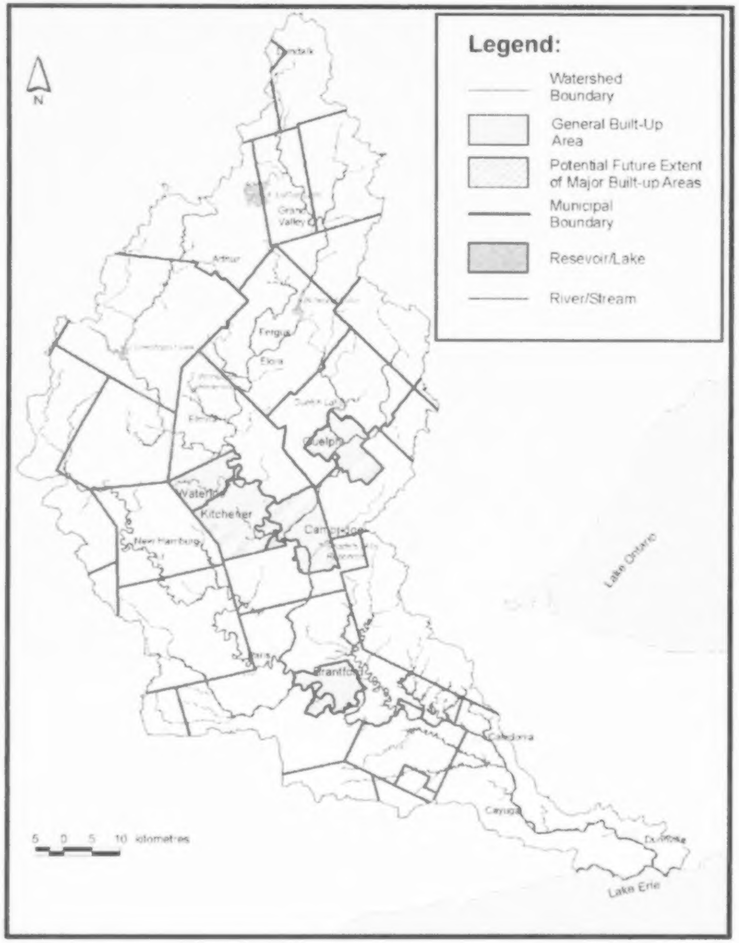
N
Legend:
Watershed Boundary
General Built-Up Area
Potential Future Extent of Major Built-up Areas
Municipal Boundary
Resevoir/Lake
River/Stream
Dundalk
Grand Valley
Arthur
Fergus
Elora
Elmira
Guelph
Waterloo
Kitchener
Cambridge
New Hamburg
Paris
Brantford
Caledonia
Cayuga
Dunnville
Lake Ontario
Lake Erie
5 0 5 10 kilometres

Figure 29.1. Location map of the Grand River watershed. Note: this figure is meant to be viewed in colour; a colour version is available at http://www.mndm.gov.on.ca/mndm/mines/ims/pub/sfw/default_e.asp .

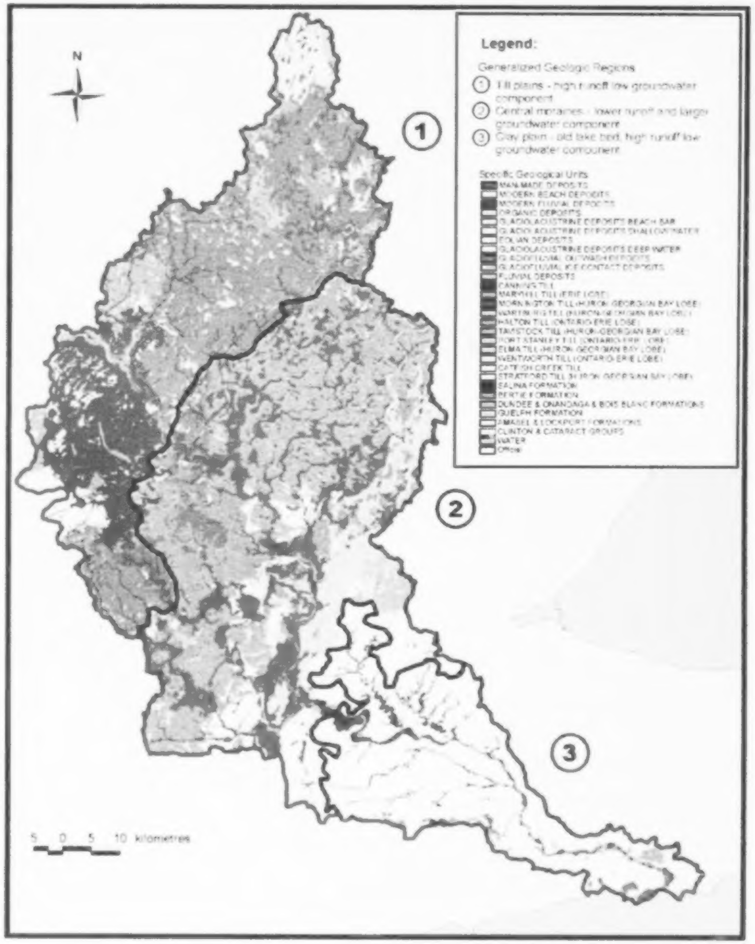
N
Legend:
Generalized Geologic Regions
① Till plains - high runoff low groundwater component
② Central moraines - lower runoff and larger groundwater component
③ Clay plain - old lake bed, high runoff low groundwater component
Specific Geological Units
MAN-MADE DEPOSITS
MODERN BEACH DEPOSITS
MODERN FLUVIAL DEPOSITS
ORGANIC DEPOSITS
GLACIOLACUSTRINE DEPOSITS BEACH BAR
GLACIOLACUSTRINE DEPOSITS SHALLOW WATER
EOLIAN DEPOSITS
GLACIOLACUSTRINE DEPOSITS DEEP WATER
GLACIOFLUVIAL OUTWASH DEPOSITS
GLACIOFLUVIAL ICE CONTACT DEPOSITS
FLUVIAL DEPOSITS
CANNING TILL
MARYHILL TILL (ERIE LOBE)
MORNINGTON TILL (HURON-GEORGIAN BAY LOBE)
WARTBURG TILL (HURON-GEORGIAN BAY LOBE)
HALTON TILL (ONTARIO-ERIE LOBE)
TAVISTOCK TILL (HURON-GEORGIAN BAY LOBE)
PORT STANLEY TILL (ONTARIO-ERIE LOBE)
ELMA TILL (HURON-GEORGIAN BAY LOBE)
WENTWORTH TILL (ONTARIO-ERIE LOBE)
CATFISH CREEK TILL
STRATFORD TILL (HURON-GEORGIAN BAY LOBE)
SALINA FORMATION
BERTIE FORMATION
DUNDEE & ONANDAGA & BOIS BLANC FORMATIONS
GUELPH FORMATION
AMABEL & LOCKPORT FORMATIONS
CLINTON & CATARACT GROUPS
WATER
Other
①
②
③
5 0 5 10 kilometres

Figure 29.2. Quaternary geology map for the Grand River watershed. Note: this figure is meant to be viewed in colour; a colour version is available at http://www.mndm.gov.on.ca/mndm/mines/ims/pub/sfw/default_e.asp .

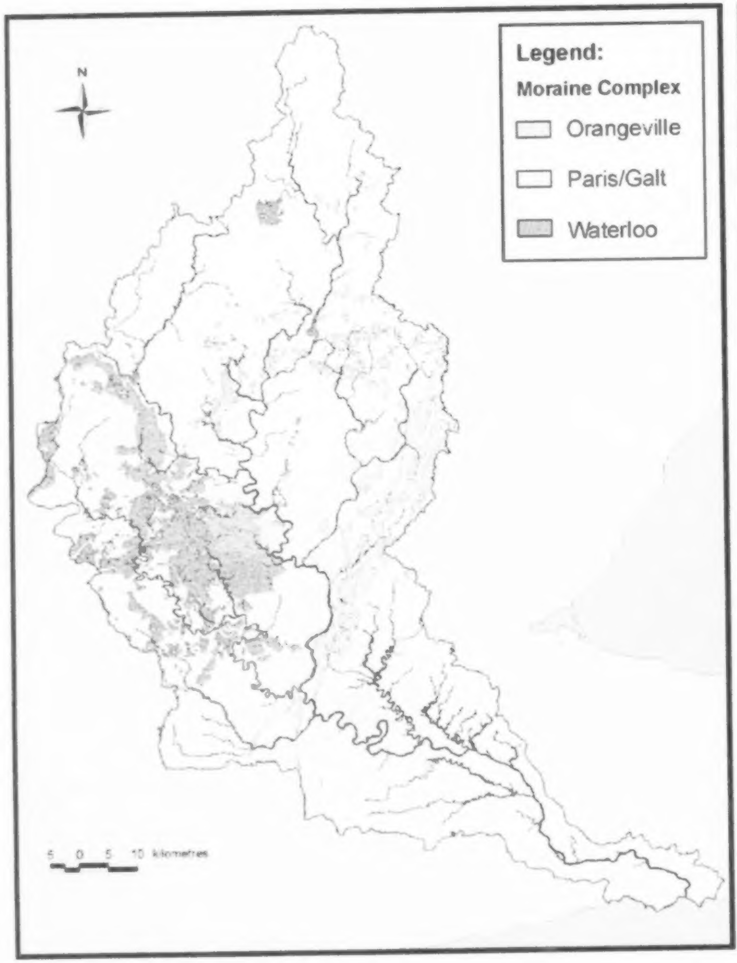
Legend:
Moraine Complex
Orangeville
Paris/Galt
Waterloo
N
5 0 5 10 kilometres

Figure 29.3. Location of moraine complexes within the Grand River watershed. Note: this figure is meant to be viewed in colour; a colour version is available at http://www.mndm.gov.on.ca/mndm/mines/ims/pub/sfw/default_e.asp .

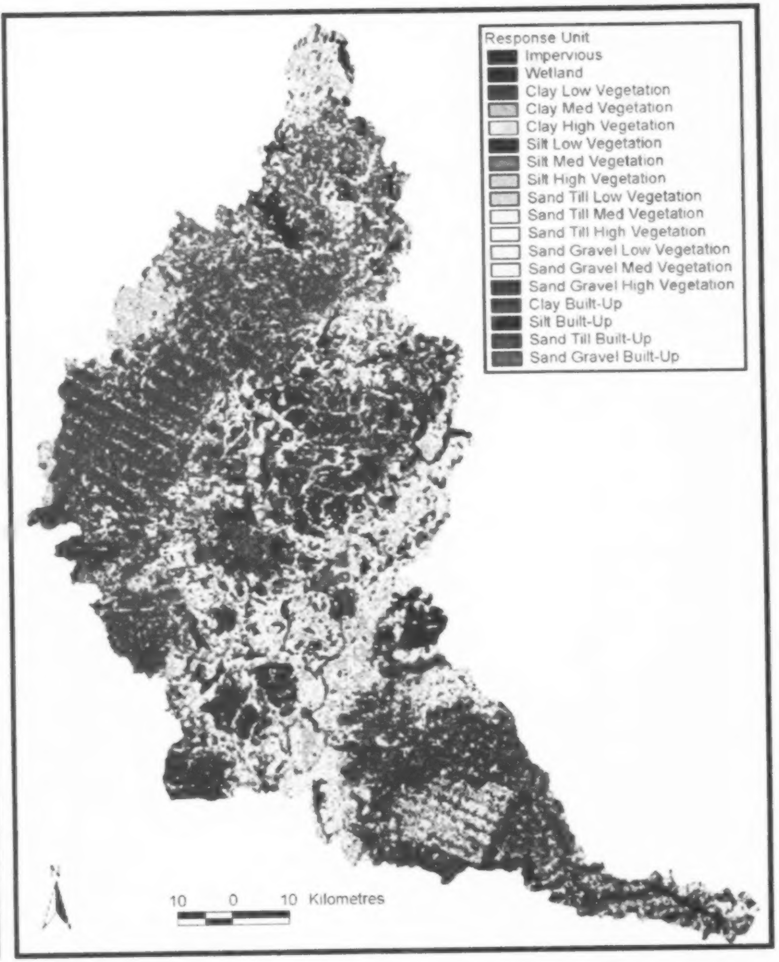
Response Unit
Impervious
Wetland
Clay Low Vegetation
Clay Med Vegetation
Clay High Vegetation
Silt Low Vegetation
Silt Med Vegetation
Silt High Vegetation
Sand Till Low Vegetation
Sand Till Med Vegetation
Sand Till High Vegetation
Sand Gravel Low Vegetation
Sand Gravel Med Vegetation
Sand Gravel High Vegetation
Clay Built-Up
Silt Built-Up
Sand Till Built-Up
Sand Gravel Built-Up
N
10 0 10 Kilometres

Figure 29.4. Hydrologic response unit for the Grand River watershed. Note: this figure is meant to be viewed in colour; a colour version is available at http://www.mndm.gov.on.ca/mndm/mines/ims/pub/sfw/default_e.asp .

SURFACE WATER MODELLING

The Quaternary geology, areas of moraines and Ministry of Natural Resources (MNR) Landsat land use information were all combined to create a hydrologic response unit coverage (Figure 29.4). This coverage represents how different areas of the watershed respond to precipitation or snow melt. Areas respond differently depending upon the underlying geology, land cover and connectivity of drainage.

This information base was used as input to the surface water model known as the Guelph All Weather Sequential Event Runoff (GAWSER). This surface water model is used to estimate water budget across the watershed on a response unit basis. It estimates the water runoff in each area, how much infiltrates into the ground and how much evaporates back to the atmosphere.

A GAWSER model based on the hydrologic response unit coverage was refined and calibrated over a three-year period from 1998 through 2001. This model is a continuous model based on hourly time series data collected from 1960 through 1999.

In recent years, efforts have focussed on presenting information from the GAWSER modelling and on water use across the watershed. The GAWSER modelling provides estimates of runoff, infiltration and evaporation for each response unit across the entire watershed. This information is being used to estimate groundwater recharge for the purpose of groundwater modelling. This work has very direct implications to source water protection. Figure 29.5 illustrates significant recharge areas across the Grand River watershed. It is based on GAWSER modelling results and the hydrologic response unit coverage. By combining this information, it was possible to identify significant recharge areas across the Grand River watershed.

Results of this work suggest that 40% of the watershed's recharge occurs in just 10% of the land area; recharge in these areas is deemed extremely high. Recharge areas classified as high or extremely high account for 70% of the total recharge and cover 30% of the watershed. Being able to quantify these significant recharge areas is extremely useful to source water protection and land use planning.

GROUNDWATER MAPPING

In parallel to the surface water program, a groundwater program was also carried out as part of the watershed plan update. The initial groundwater program focussed on the Ministry of the Environment (MOE) water well database along with OGS information as a basis upon which to build a conceptual and technical understanding of the groundwater system.

Between 1997 and 1998, contracts were awarded to update the water well database across the Grand River watershed. Waterloo Region, an upper tier municipality, had already updated the water well database in their area. The GRCA work focussed on areas outside Waterloo Region. The database update was completed in early 1999.

In the fall of 1999, a hydrogeologist and a geographic information systems (GIS) expert were hired to analyze the water well information and prepare regional-scale groundwater mapping. This mapping was prepared at 2 scales, first at a scale of 1:50 000 for the 13 map sheets covering the Grand River watershed and, second, at the scale of the entire watershed.

The maps focussed on 4 areas: physical geology characteristics, hydrogeology characteristics, surface water–groundwater interaction and groundwater susceptibility mapping. Initial maps were produced in late 1999 and a draft report in December 2000.

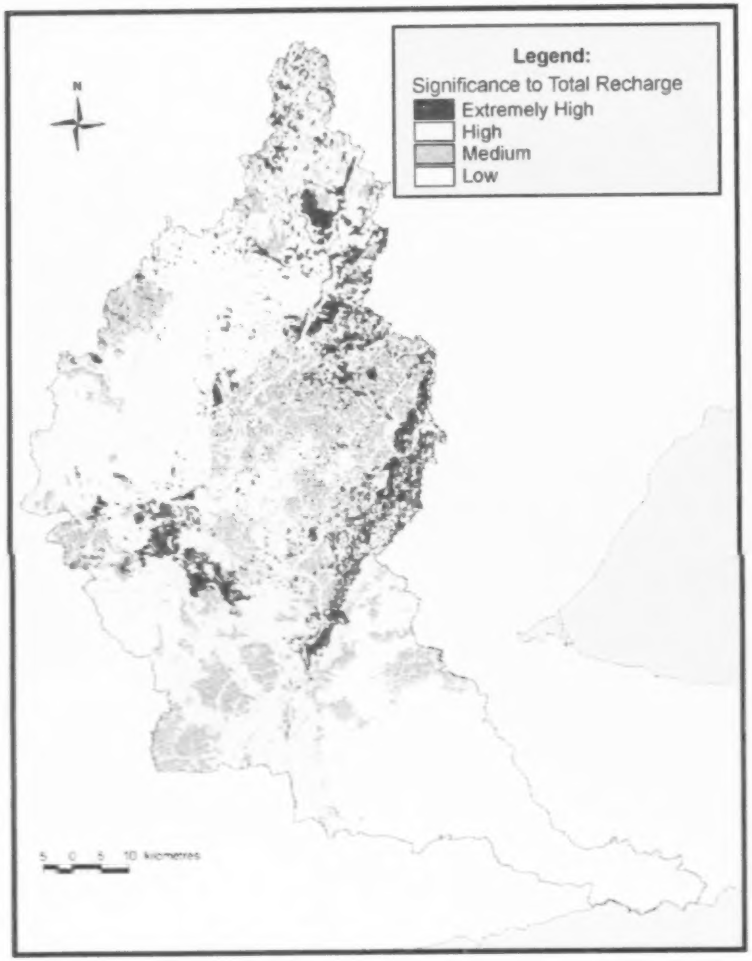
Legend:
Significance to Total Recharge
Extremely High
High
Medium
Low
N
5 0 5 10 kilometres

Figure 29.5. Significant recharge areas in the Grand River watershed. Note: this figure is meant to be viewed in colour; a colour version is available at http://www.mndm.gov.on.ca/mndm/mines/ims/pub/sfw/default_e.asp .

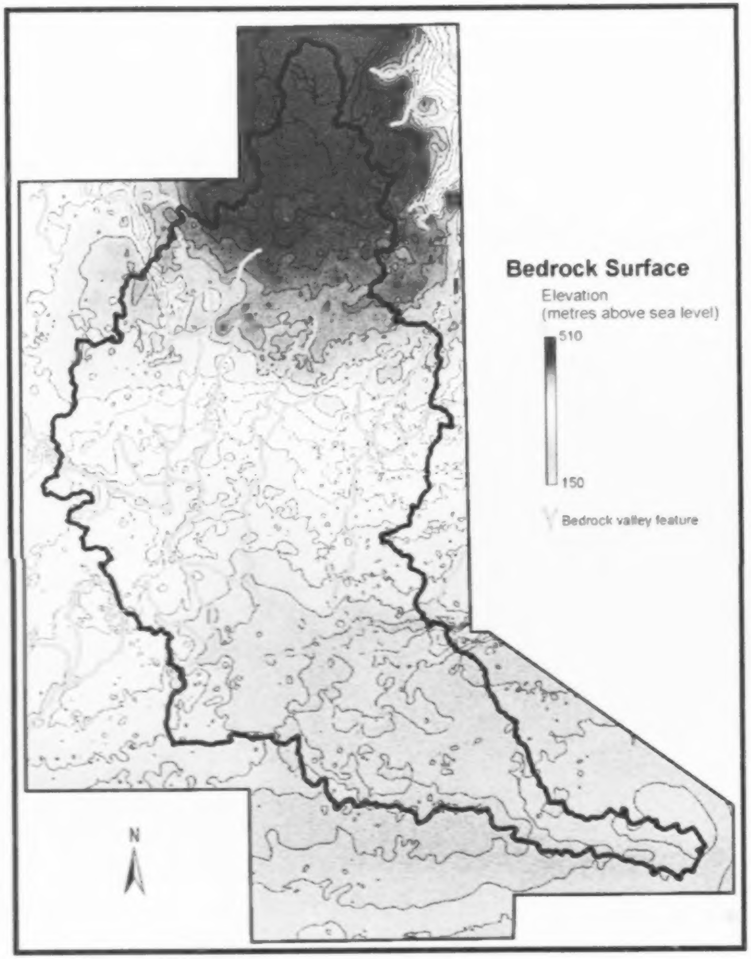
Bedrock Surface
Elevation
(metres above sea level)
510
150
Bedrock valley feature
N

Figure 29.6. Location of bedrock valleys which formed the preglacial paleo-drainage system in the Grand River watershed. Note: this figure is meant to be viewed in colour; a colour version is available at http://www.mndm.gov.on.ca/mndm/mines/ims/pub/sfw/default_e.asp .

The physical geology characteristics that were collected included bedrock surface, overburden thickness, and areas of significant sand and gravel thickness across the watershed. The bedrock surface mapping inferred locations of potential bedrock valleys, which formed the preglacial paleo-drainage underlying the watershed. This was the first time such features had been identified. The paleo-drainage was illustrated on a watershed basis thereby illustrating major bedrock valleys that could influence the movement of groundwater in the Grand River watershed (Figure 29.6).

The hydrogeology portion of the report focussed on the shallow water-table surface, deep or potentiometric water surface and on hydraulic recharge and discharge areas across the watershed. The section of the report on groundwater–surface water interaction generated maps illustrating locations where the shallow groundwater table lay above the ground surface. This mapping, for the first time, helped identify areas of potential groundwater discharge across the watershed. This complemented work completed for the Grand River fisheries management plan.

The final component of the regional groundwater study examined the susceptibility of groundwater to surface water contamination. At the time, groundwater susceptibility mapping was in its infancy in southern Ontario. Some simple techniques were applied to identify areas potentially susceptible to contamination.

The regional groundwater study was a major step to developing a good technical understanding of the groundwater system across the Grand River watershed. The study formed the basis for approaches that are now being applied in other parts of southern Ontario and in several of the MOE municipal groundwater protection studies.

Although the regional groundwater study advanced the understanding of the groundwater system, it also identified gaps. To truly understand the groundwater system, three-dimensional (3-D) regional geological and hydrogeological information is needed. This information would form the foundation upon which to build a conceptual geological model and the basis for 3-D groundwater modelling.

OTHER CURRENT ACTIVITIES

Groundwater Modelling

Understanding the 3-D aspects of the geology underlying the ground surface in the Grand River watershed is fundamental to good resource management. Initial steps toward this goal have already begun. The OGS funding of groundwater resources inventory projects is working toward the goal of developing the first digital 3-D conceptual model of the surficial geology across southern Ontario. It will take time to complete this effort, but will be of enormous benefit once completed.

In the Grand River watershed, the OGS is funding the "Grand River Groundwater Modelling Project". This project is developing a 3-D numerical groundwater model across the Grand River watershed. This will be the first attempt to model the groundwater system as a whole across the watershed.

In preparation for this modelling work, oil and gas well drilling records were organized for the watershed to improve the interpretation of the bedrock surface underlying the watershed. A baseflow survey was also carried out to investigate the presence or absence of baseflows across the northern half of the watershed.

The results of the current work will further the technical understanding of groundwater and geology in the Grand River watershed. It is expected that this work will be used to prioritize efforts to improve and refine the conceptual geology model and initial groundwater flow models. The regional model will provide boundary conditions for other models at sub-watershed scales.

Of great benefit is the OGS work to update the Quaternary mapping in Waterloo Region and develop a 3-D conceptual model of the Waterloo Moraine (Bajc, this volume). The Waterloo Moraine acts as one of the primary water sources for the cities of Kitchener and Waterloo, supplying a population of 350 000 residents.

Groundwater Monitoring Network

The Ministry of the Environment (MOE) is funding a provincial groundwater monitoring network and working in partnership with Ontario conservation authorities to implement this network across Ontario. This network will record groundwater level over time. The information will be used to calibrate groundwater models and help better understand groundwater flow systems.

Within the Grand River watershed, the development of new wells as part of this network provide the opportunity to establish high-quality logging of wells that will assist in the development of conceptual geological models for different areas of the watershed.

Existing OGS geological information played a fundamental role in deciding where to site new monitoring wells in the Grand River watershed. Additionally, funding from the groundwater resource inventory projects has allowed "high-quality " geological boreholes to be installed as part of this network development.

Ministry of the Environment Groundwater Protection Studies

Several groundwater protections studies, funded by the Ministry of the Environment (MOE), have been completed or are ongoing throughout the watershed. These studies are typically completed on a municipal basis and focus on groundwater protection.

The Grand River groundwater model, under the OGS groundwater resource inventory program, is a first step to pull together information from the studies funded by MOE into a regional framework. The regional framework will span municipalities to create a seamless information base.

Surface Water Modelling and Water Budget Analysis

Work continues to refine the water budget model for the Grand River watershed. Currently, water use information is being updated and refined to provide a more precise estimate of water use.

The MOE has funded an assessment of ecological in-stream flow requirements. Three pilot projects have been funded to date in conservation authorities across southern Ontario. One of the pilot projects is located within the Grand River watershed. Various in-stream flow techniques will be applied in different areas of the Grand River watershed to estimate the water requirements of the natural environment. Geological information is being applied to help characterize these flow systems.

The MOE is also funding the development of a variable source area model. A variable source area model would produce similar results to those of the current GAWSER model applied in the Grand River watershed. The new variable source area model would be based on provincially available information to allow for its application across the province along with tools to help setup and calibrate the model. Information from the groundwater modelling study will be used to update and refine the surface water model.

Source Water Protection

The work done to develop a management plan for the Grand River watershed has established the components of a source water protection plan for the watershed. As source water protection planning is implemented, components of the existing watershed plan will be adapted to meet the source water protection requirements. The digital Quaternary geology base across southern Ontario will play a major role in the development of effective source protection plans in Ontario. More information on the activities described within this report is available at the Grand River Conservation Authority web site www.grandriver.ca.

OFR 6120 ***Summary of Field Work and Other Activities 2003***
Article 30 figures are meant to be viewed in colour; colour versions are available at
http://www.mndm.gov.on.ca/mndm/mines/ims/pub/sfw/default_e.asp .

30. Project Unit 03-020. Groundwater Resource Inventory Papers (GRIPs) for the Oak Ridges Moraine Area

S. Holysh[1] and S.D. Davies[1]

[1]Conservation Authorities Moraine Coalition

INTRODUCTION

In 2001, the Sedimentary Geoscience Section (SGS) of the Ontario Geological Survey (OGS) received funding to undertake the initial phase of an "Aquifer Mapping and Susceptibility to Contamination" program under the province's Clean Water Strategy. For the fiscal years 2002–2003, and 2003–2004, additional funding was approved to continue this aquifer-mapping program. The program contributes to the 4 main areas of the province's Clean Water Strategy, namely 1) groundwater information, 2) source protection, 3) managing water taking and 4) reducing risks.

The City of Toronto, the Regional Municipalities of York, Peel and Durham and their associated conservation authorities are partners in the Conservation Authorities Moraine Coalition (CAMC). This partnership was formed in 2000 with a long-term goal of understanding the groundwater system across a large portion of southern Ontario. One objective of the CAMC partnership is to increase the level of understanding of groundwater flow conditions across the Oak Ridges Moraine (ORM) to allow for informed land use decision making. Through the CAMC, a number of technical and policy studies have been initiated, which can be classified under 4 main areas: 1) data management, 2) data collection, 3) technical analyses and 4) policy and planning.

In 2003, the OGS partnered with the CAMC to complete Groundwater Resource Inventory Papers (GRIPs) for the 9 conservation authorities whose jurisdictions cover the ORM. This article discusses the initial work undertaken in support of these GRIPs.

BACKGROUND

In watersheds, groundwater is an integral component of the hydrological environment. Groundwater provides base flow to many southern Ontario streams, thereby sustaining aquatic ecosystems. As one example, groundwater discharge to streams is required in order to maintain cold-water fisheries habitat. Groundwater is also the main source of drinking water for many communities and individual residences, and provides critical water supplies to some industrial and commercial operations. Understanding the regional groundwater system is critical to adequately managing and protecting the resource for continued societal benefits.

In 2001, CAMC initiated the construction of a three-dimensional numerical groundwater model to better characterize the regional groundwater system. This work involved the compilation and collection of many data sets, including the in-depth interpolated stratigraphy of the Geological Survey of Canada

Summary of Field Work and Other Activities 2003,
Ontario Geological Survey, Open File Report 6120, p.30-1 to 30-8.

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(GSC) (Sharpe et al. 1999), the Ministry of Environment (MOE) water well record database, and key borehole logs and aquifer parameter data in accessible consultant reports. All of these data sets were stored within an Microsoft® Access database and interpreted using Viewlog® software.

The work being carried out by the CAMC in many ways fits the requirements of the GRIP reports and, therefore, allows for additional field work to be completed to fill in key data gaps. The field program undertaken to date is summarized below.

The 9 watersheds (with the corresponding conservation authorities) for which the GRIPs are being completed in partnership with CAMC are illustrated in Figure 30.1.

REGIONAL GEOLOGICAL SETTING: THE OAK RIDGES MORAINE

The Oak Ridges Moraine (ORM) stretches approximately 160 km across southern Ontario from the Niagara Escarpment in the west to the Trenton area in the east (*see* Figure 30.1). The ORM is a significant physiographic feature and serves as the height of land separating southward-flowing drainage toward Lake Ontario from northward-flowing drainage toward Lake Simcoe. The ORM provides water to more than 30 major streams and many communities on the ORM obtain potable water from its aquifers.

The ORM consists of a complex glacial succession of coarse-grained sediments (aquifers) and fine-grained tills (aquitards), with southwest-trending channels that dissect the lower portions of the overburden package. The entire area is underlain by Paleozoic bedrock. The overburden sediments within the moraine originated from glacial, glaciolacustrine and nonglacial events during the last 125 000 years (Karrow 1989).

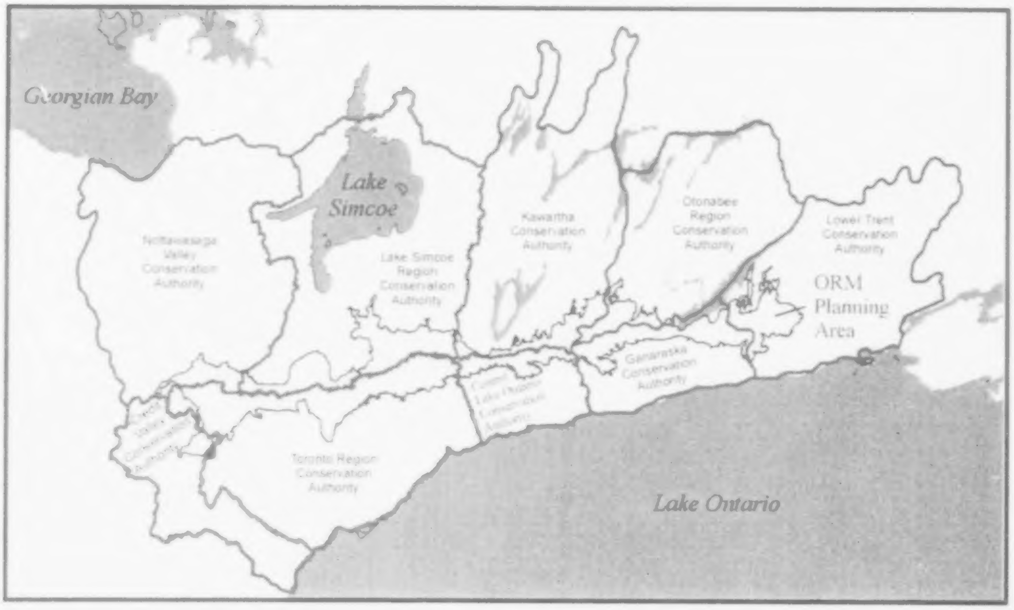
Georgian Bay
Lake Simcoe
Nottawasaga Valley Conservation Authority
Lake Simcoe Region Conservation Authority
Kawartha Conservation Authority
Otonabee Region Conservation Authority
Lower Trent Conservation Authority
ORM Planning Area
Ganaraska Conservation Authority
Central Lake Ontario Conservation Authority
Credit Valley Conservation Authority
Toronto Region Conservation Authority
Lake Ontario

Figure 30.1. Location of watersheds studied and conservation authorities covering the Oak Ridges Moraine.

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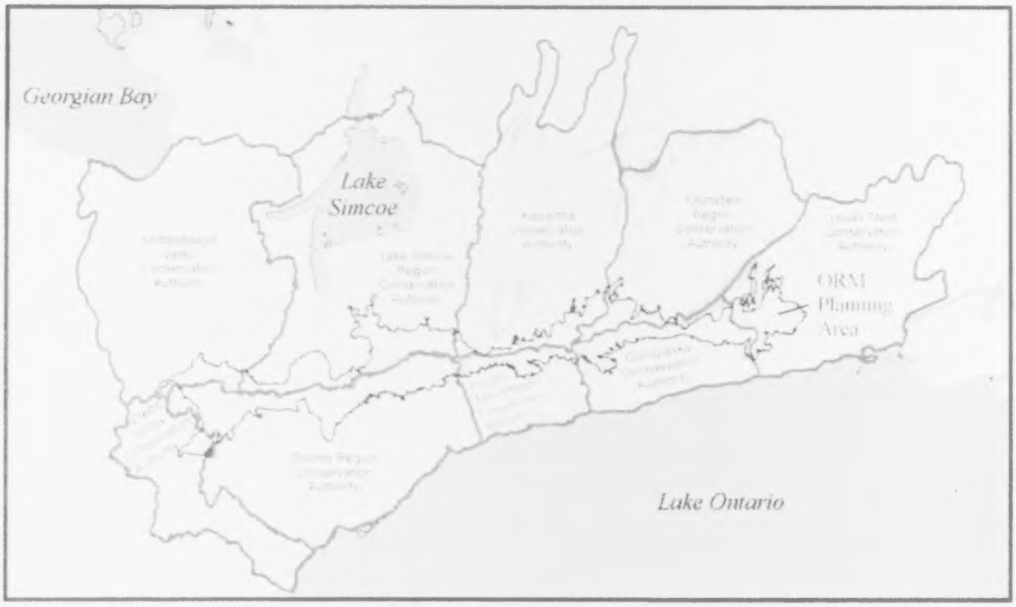

Georgian Bay
Lake Simcoe
Nottawasaga Valley Conservation Authority
Lake Simcoe Region Conservation Authority
Kawartha Conservation Authority
Ganaraska Region Conservation Authority
Lower Trent Conservation Authority
ORM Planning Area
Toronto Region Conservation Authority
Lake Ontario

Figure 30.1. Location of watersheds studied and conservation authorities covering the Oak Ridges Moraine.

The exact origin of the ORM is the subject of ongoing debate. In the 1990s, the GSC constructed a conceptual geological model of the ORM which has significantly advanced the understanding of its formation (Sharpe et al. 1999; Logan, Russell and Sharpe 2001). The GSC model subdivided the overburden stratigraphy of the ORM into 5 units: 1) the lower deposits, 2) Newmarket Till, 3) Oak Ridges Moraine sediments, 4) Halton Till and 5) glaciolacustrine and more recent deposits (Figure 30.2).

An unconformity forms the upper surface of the Newmarket Till and is of significant importance in the understanding the overburden geological sequence (Barnett et al. 1998). The surface of the Newmarket Till is drumlinized and is breached by a series of tunnel channels. Depending on the intensity of individual events, these tunnel channel features can 1) erode partially into the Newmarket Till; 2) erode through the entire Newmarket Till into the lower sediments; or 3) erode through the lower sediments to the bedrock surface. From a hydrogeological perspective, these channels can connect shallow aquifers in the upper parts of the ORM with deeper aquifer systems in the lower sediments.

Also of significance from a hydrogeological perspective is the fact that the bedrock surface reflects the erosion of the Laurentian Channel system, a long standing alluvial system connecting Georgian Bay with Lake Ontario (Eyles, Boyce and Mohajer 1993). This bedrock feature has not yet been mapped in detail, but is likely a deep valley feature. Depending on the nature of its infill, this significant bedrock valley could be conducting groundwater beneath the ORM, as well as directing significant quantities of groundwater towards Lake Ontario.

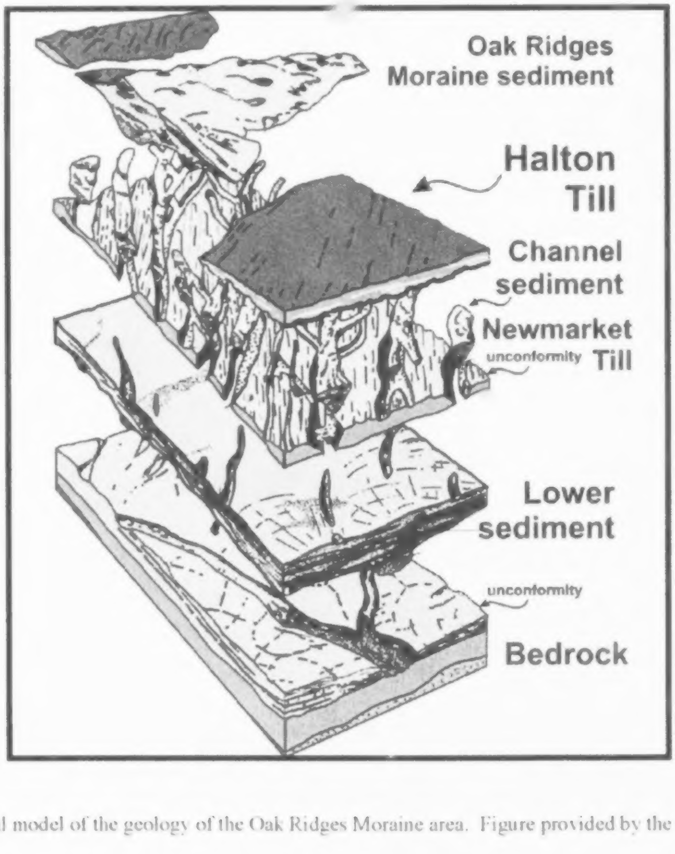

Figure 30.2. Conceptual model of the geology of the Oak Ridges Moraine area. Figure provided by the Geological Survey of Canada.

2003 FIELD PROGRAM

General Field Activities

For the 2003 field season, 3 field staff were retained to work in 3 conservation authorities where hydrogeological field data were sparse: Nottawasaga Valley Conservation Authority, Ganaraska River Conservation Authority and Lower Trent Conservation Authority. One staff member was based at each of the respective conservation authority offices. The mandate of each staff member was to document, compile and summarize key historical hydrogeological data, and to collect new field data during the field season.

In 2003, more than 300 technical reports from the 3 conservation authorities (in addition to Kawartha Conservation Authority, Otonabee Conservation Authority and Lake Simcoe Region Conservation Authority) were scanned. These scanned reports were added to a web-based server that is currently available to the CAMC partners. Previously, more than 1000 reports had been scanned from the Greater Toronto Area. All of these reports are being geo-referenced. Pertinent data contained within the reports, (e.g., detailed borehole data, hydraulic parameter data) are being retrieved and added to a comprehensive hydrologic database (using Microsoft® Access) that has been built for the project. This database currently contains nearly 150 000 water well records with the associated temporal data (such as pumping rates and water level information). The database also contains stream flow information and climate data.

Field work completed in each of the 3 conservation authority areas includes

- stream baseflow measurements at key locations
- collection of continuous stream temperature data during warm or hot weather conditions using temperature data loggers
- mapping of headwater streams to estimate the intersection of the groundwater table and the ground surface

These field activities were generally focussed on the Nottawasaga Valley Conservation Area, Ganaraska River Conservation Authority and the Lower Trent Conservation Authority, although some data were also collected in Lower Simcoe Valley Conservation Authority and Central Lake Ontario Conservation Authority watersheds.

In total, 271 baseflow measurements of different stream sections were collected, 363 locations were visited in order to map the origin of different headwater streams and continuous surface water temperature surveys were completed at 101 locations. The stream temperature surveys were completed in cooperation with the Ministry of Natural Resources (MNR) as part of its ongoing habitat survey program. The data will be made available to MNR for inclusion in its database. All of the data are currently being compiled and analyzed for inclusion into the overall database. These data will aid in the understanding of the groundwater flow system in the areas studied and will provide detailed calibration targets for the numerical groundwater flow model. Figure 30.3 shows the locations of the various field measurements undertaken during the 2003 field season.

Laurentian Channel Investigations

The Laurentian Channel system is a regional unconformity directly overlying the bedrock surface, extending from Georgian Bay to Lake Ontario (Spencer 1881). It is a deeply buried bedrock valley infilled with sediments interpreted to represent a preglacial subaerial river system. The system itself is overlain by sediments up to 200 m thick. The Laurentian Channel system has not yet been well delineated, partially because of the relatively thick overburden sequence that overlies and fills in the feature. However, portions of the system are thought to contain productive aquifers and may strongly influence the groundwater flow system in a broad band extending beneath the ORM.

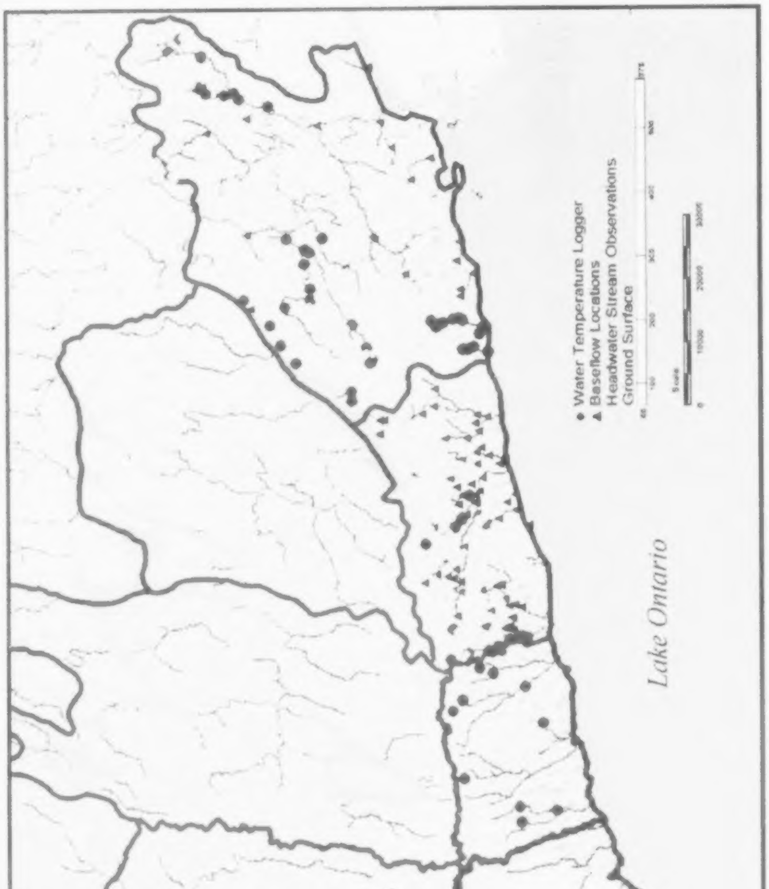
Georgian Bay
Lake Simcoe
Lake Ontario
● Water Temperature Logger
▲ Baseflow Locations
Headwater Stream Observations
Ground Surface
65
100
200
300
400
500
Scale
0
10000
20000
30000

Figure 30.3. Locations of baseflow measurements, stream temperature surveys and headwater mapping completed in 2002 and 2003.

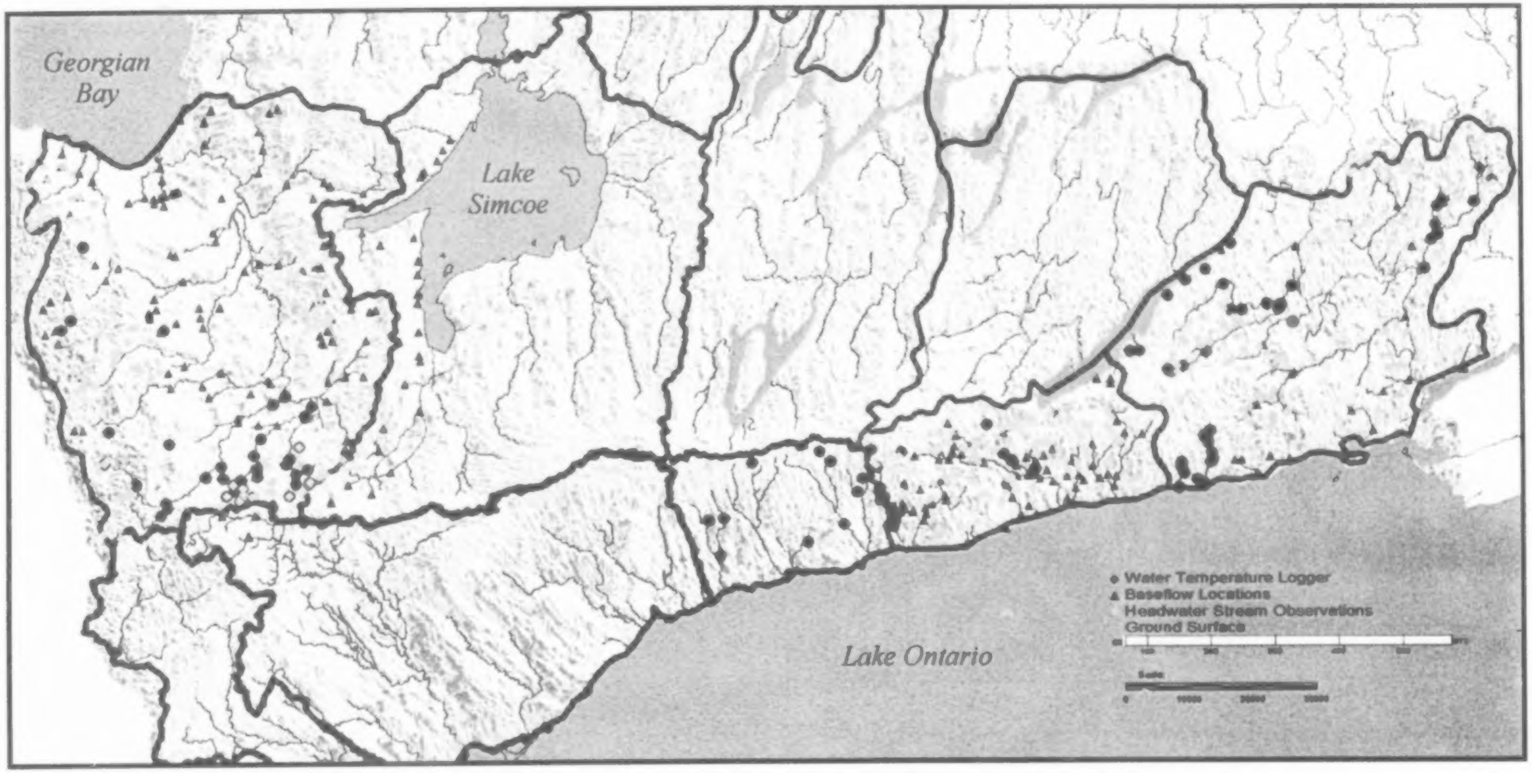
Georgian Bay
Lake Simcoe
Lake Ontario
● Water Temperature Logger
▲ Baseflow Locations
Headwater Stream Observations
Ground Surface
Scale

Figure 30.3. Locations of baseflow measurements, stream temperature surveys and headwater mapping completed in 2002 and 2003.

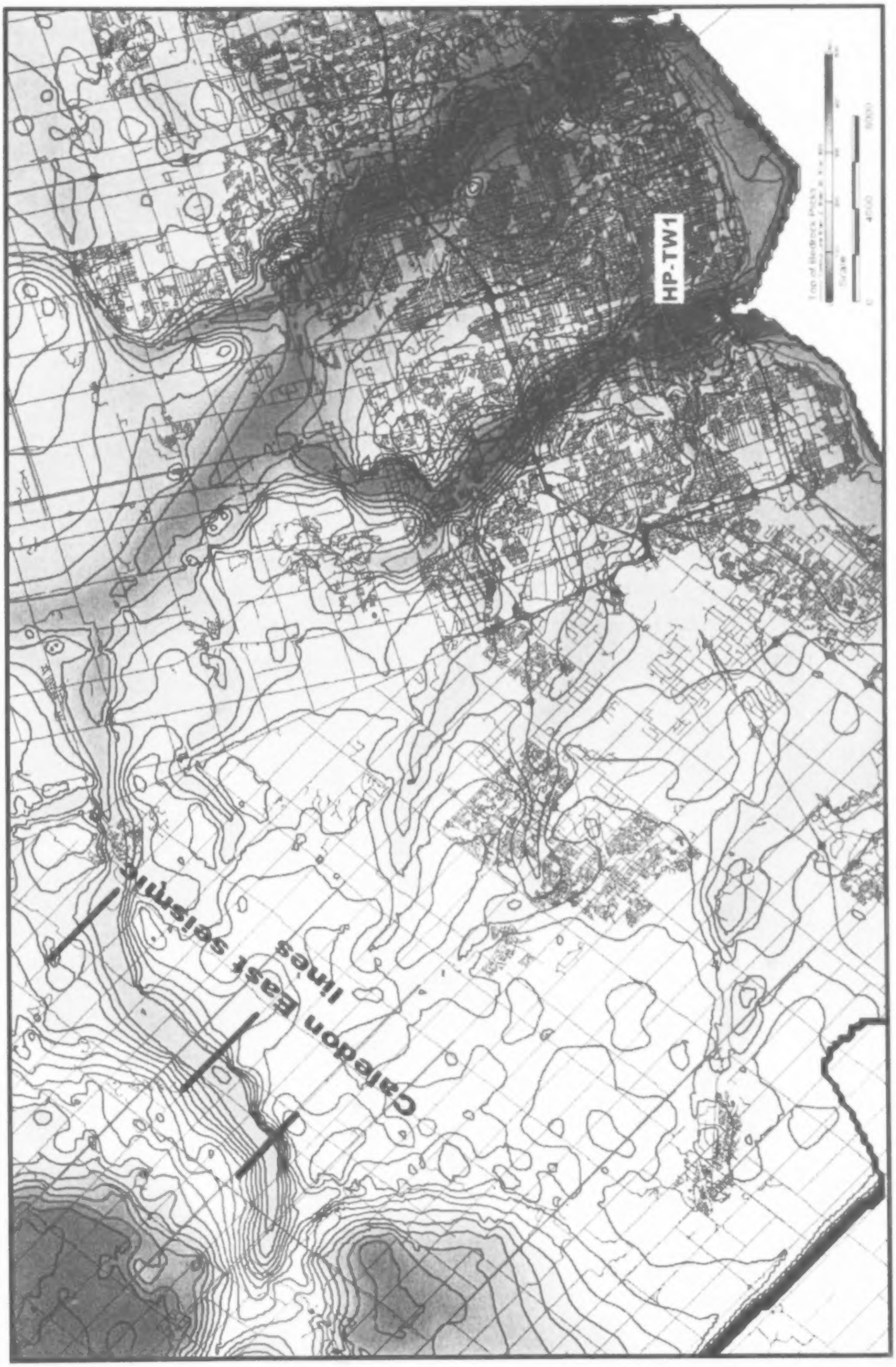
HP-TW1
Caledon East seismic lines
Top of Bedrock Picks
Scale
0
4500
9000

Figure 30.4. Location of High Park borehole (HP-TW1) and 3 seismic lines in the Caledon East area superimposed on an interpolation of the bedrock surface. Darker areas are bedrock lows.

In 2003, the Laurentian Channel system was investigated through 2 field projects: 1) the drilling of a deep, high-quality borehole near the channel's expected outfall to Lake Ontario, at High Park in Toronto; and 2) the completion of 3 seismic lines in the Caledon East area, where a very deep bedrock valley was intersected in 2002 as part of a field program completed by CAMC in partnership with the Credit Valley Conservation Authority. The locations of the High Park borehole and Caledon East seismic lines are illustrated in Figure 30.4. An interpolation of the bedrock surface with the Laurentian Channel system imposed through all of the known bedrock lows, as well as through deep overburden wells that did not intercept bedrock, is also shown on Figure 30.4.

The drilling of the High Park borehole was done in partnership with the City of Toronto. It originated from a program to decommission 2 old artesian wells that were discovered during recent work on sedimentation ponds along Spring Road in High Park. Little information is available on the age, stratigraphy, construction details and depth to bedrock of these 2 wells. However, due to their strategic location relative to the Laurentian Channel system and their artesian conditions, it was decided to drill another well in this area and to install a monitoring well in this borehole. The purpose of this work was to investigate the nature of the Laurentian Channel system at its interpreted terminus, to record the long-term hydraulic behaviour of the channel system and to investigate groundwater quality. Drilling was completed during July and August 2003.

An initial borehole was completed using the PQ coring system. During drilling, strong artesian conditions were encountered with water, coarse gravel and cobbles discharging from the drill hole. Flow from the well was controlled using packers and an attempt was made to grout in the hole. During the grouting, springs developed nearby. As a result, the well was once again allowed to flow freely to inhibit further springs from developing. A second well was completed nearby using a Barber-style water-well rig. This second well was pumped in order to bring hydraulic heads below ground surface, allowing the first well and the springs to be grouted using a Schlumberger grouting system. The pumping well continues to be actively pumped as the construction of the sedimentation ponds is completed. Photo 30.1 illustrates the artesian conditions encountered during the drilling program.

Bedrock was reached during the drilling of the second well at 145 m below ground surface. Hydraulic data are being collected to further investigate the nature of the artesian conditions and the data are presently being analyzed. The age of the water from the artesian aquifer is also currently being investigated through isotope testing. Staff at the University of Waterloo are completing this work.

The results of the seismic work in the Caledon East area have not been fully synthesized; however, preliminary results indicate a significant, deep bedrock valley that trends in a northeast direction. This valley may represent a significant tributary of the preglacial Laurentian channel.

FUTURE WORK

A number of field programs are planned for the remainder of 2003 and 2004. These programs would address key data gaps in the three-dimensional hydrogeological model of the Oak Ridges Moraine, as part of this GRIP program. Work being considered includes the following:

- collection of strategic baseflow, stream temperature and headwater data from Otonabee and Kawartha conservation authorities
- completion of additional boreholes to bedrock at strategic locations, including 1) near Rice Lake (in an interpreted tunnel channel) and 2) in the Region of York (where 3 boreholes may be drilled across the width of a tunnel channel)
- additional seismic work at strategic locations, including across a tunnel channel near Lake Scugog and across the Laurentian Channel system in the King City area

Photo 30.1. Artesian conditions encountered during the drilling of the High Park borehole in Toronto.

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Geoscience Program Initiative

31. Ontario Mineral Exploration Technologies (OMET) Program

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INTRODUCTION

Announced by the Ministry of Northern Development and Mines in September 2000, the Ontario Mineral Exploration Technologies (OMET) Program is a four-year, $8.0 million initiative to develop and test innovative mineral exploration technologies and methods. The goal is to enhance the efficiency of the exploration firms in high potential geological areas of Ontario. Significant progress has been achieved in the past 3 years with the approval of 21 projects for funding. The new technologies and methods developed will increase Ontario's attractiveness to mining and mineral exploration by funding high-potential projects that are targeting Ontario's mineral exploration challenges.

As at June 30, 2003, approximately $5.8 million has been awarded to projects that have undergone assessment reviews and approval recommendation by the Expert Technical Advisory Committee (ETAC).

SUMMARY OF APPROVED PROJECTS

Table 31.1 summarizes descriptions of the 21 approved OMET projects. Two proposals that were conditionally approved are not included in the descriptions below.

Table 31.1. Approved OMET projects.

Proposal #, Name and Title	Project Goals	Exploration Challenge Addressed
P01-02-001 Camiro **Detectability of mineral deposits with airborne gravity**	To model ore deposit responses from airborne gravity data.	The challenge is to refine the target-discrimination potential of airborne gravimetry. This research will further the understanding of: the expected responses of economic targets, the masking of geological noise, the detectability versus depth relationship, and the system specifications of airborne gravity instruments for detection of ore bodies.
P01-02-002 Camiro **Three dimensional surficial geochemistry**	To determine by field trials which form of metal transport is most likely to be at work for a given area. The result being reduced sample densities and less test parameters.	Surficial geochemistry in areas of thick overburden cover has always presented a challenge to mineral exploration. By systematically studying the natural processes at work at selected sites, the sampling effectiveness and mineral discovery rate in overburden areas will be enhanced.

Summary of Field Work and Other Activities 2003,
Ontario Geological Survey, Open File Report 6120, p.31-1 to 31-6.

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Table 31.1. continued

Proposal #, Name and Title	Project Goals	Exploration Challenge Addressed
P01-02-003 Camiro **The use of soil gas hydrocarbon technique to differentiate barren from ore-bearing conductors**	To use laboratory experiments determine which organic compounds are related to which ore type. Field studies will sample B-horizon soils over different types of conductive bodies. Comparison will be made between the controlled laboratory studies and field studies.	The challenge for explorationists is to distinguish between barren electromagnetic conductors and mineralized electromagnetic conductors. The project is expected to provide an effective and cost-efficient tool for locating and distinguishing between mineralization types types.
P01-02-007b Geotech **Modeling, interpretation methods and field trial of an existing prototype AFMAG system**	To develop and test by field trials an extremely low frequency (ELFMAG) with high sensitivity multiple-frequency digital system for airborne and ground surveys.	Thick conductive overburden and Paleozoic cover rocks have presented a barrier to traditional electromagnetic methods. This method is expected to provide the capabilities to look deeper at acceptable costs. It will have the potential to map conductive bodies to depths of 1000 m.
P01-02-008a GSC **Three dimensional geochemistry in the Abitibi**	To develop and document a soil geochemical technique for the Abitibi Clay Belt to locate base metal and gold deposits.	The Abitibi Clay Belt with thick and exotic cover has resulted in costly exploration work in the area. The clarification and identification of element migration pathways and fixation in the near surface will allow explorers to locate base metal and gold mineralization through tens of metres of glacial sediments in a cost-effective manner.
P01-02-011a Ferra Dynamics **Technology development of a high bandwidth helicopter EM system**	To test a concept that may triple the sample density of HEM system in order to more accurately map glacial sediments and identify conductive bodies underneath them.	Conductive sediments in many regions of Ontario have masked the electromagnetic responses of conductive ore bearing rocks. This research project will develop, test and prove the acquisition technology so that commercial surveys may be flown using this technology. The technology will be a step toward a basis of one capable of penetrating deep clay belts.
P01-02-014 Quantec **Demonstration survey of the distributed acquisition method MT/IP earth imaging technology**	A prototype system will be demonstrated to show that it will quantitatively map lithology, structure, alteration, and mineralization. The data collected will be interpreted using 3D earth models with GoCAD.	The challenge is to demonstrate the technology in a variety of geological environments and over several control sites in northern Ontario. The technology is designed to detect mineralization to depths of 1000 m in areas of glacial cover. The new technology will be capable of mapping the bedrock geology.
P01-02-016a University of Ottawa **Geochemical detection of buried and disseminated palladium mineralization in northwestern Ontario**	The research will target mafic and ultramafic igneous rock complexes in the search for palladium and platinum using pathfinder elements.	A new type of platinum group metal deposits has emerged in Ontario. The challenge is to identify possible ore bearing rocks when there is no clear geophysical signature. Commercial assaying methods are expensive with high detection limits and have limitations in targeting potential areas. The research will examine alteration, dispersion, solubility, leaching, and precipitation barriers. The result will be concepts for geochemical exploration and anomaly definition.
P01-02-018 York University **Geodata Analysis Systems (GEODAS) for mineral exploration in Ontario**	The goal of this research is to demonstrate the GeoDas methodology and feasibility to produce a state-of-the-art GIS-based technology for predictive mineral potential mapping.	The generation of mineral exploration targets especially in areas of thick overburden cover has become increasingly difficult because of the highly diverse and complex data sets. GeoDas has the capability and functionality to handle this challenge.
P01-02-021 Quantec **Airborne hyperspectral surface mapping over exposed and covered mineral belts in Ontario**	This project will evaluate the capabilities of the hyperspectral sensor and software for detecting rock alteration that may be indicative of 'blind' ore deposits.	This project will address the need to be able to systematically and efficiently collect hyperspectral data from an aircraft. The result being the demonstration of a new tool for geologic mapping and definition of new prospective terrain for mineral exploration.

Table 31.1. continued

Proposal #, Name and Title	**Project Goals**	**Exploration Challenge Addressed**
P01-02-023 Mira Geoscience **3D data integration methodology and tools for in-mine and near-mine exploration**	Demonstration of new 3D data interpretation method and software through case studies, using rock property modelling, and geochemical and geophysical data to maximize success in targeting diamond-drill holes.	In areas of complex geology, the challenge is to integrate and interpret the wealth of data collected during exploration in and near mine sites. This new software will deliver an efficient and cost-effective means to target diamond-drill holes, which will lead to successful mineral exploration and the discovery of new ore reserves.
P01-02-005b Gedex **Gedex AGG (airborne gravity gradiometer) system**	This project focusses on research, development and testing of system components of a prototype high-resolution gravity gradiometer.	Currently, the only available airborne gravity system does not have the sensitivity required for the majority of mineral deposits. The Gedex AGG system will provide rapid, airborne data collection that will have significantly greater sensitivity and bandwidth enabling it to find deposits that are invisible to other systems.
P02-03-025 T. C. Barrie and Associates **Geochemistry of graphitic argillites and iron formation near VMS and gold deposits**	This research project will investigate geochemical and geophysical characteristics of interflow sedimentary graphitic argillites and iron formations. The resultant signatures and mineral potential mapping will target mineral deposits undercover.	The project will provide useful databases on graphitic argillites and iron formations; it will provide new methodologies for use in geochemical exploration in area of thick glacial cover. The alteration haloes associated with ore deposit can be recognized up to 1 km from the ore deposit using this geochemical method.
P02-03-028 JVX Ltd. **Diamond-drill hole spectral IP for poorly conducting copper/PGM mineralization in the Sudbury Basin**	This research project will demonstrate the borehole spectral IP methods to identify and model disseminated footwall sulphide and vein systems in the Sudbury Basin.	The exploration challenge is to locate and create 3D models of non-conducting sulphide zones that have the potential to carry significant platinum group metals. The outcome is the identification of diamond drill targets that are missed by conventional geophysical methods.
P02-03-031 Mira Geoscience **The downhole seismic imaging method: a new tool for deep mineral exploration**	This project will demonstrate a new tool for mineral exploration for location orebodies, lithological contacts and structures at a distance of up to 1 km from boreholes at depths up to 2000 m.	The downhole seismic imaging (DSI) method will transfer a technology from academic research to industry as a new tool for mineral exploration. The placement of geophones in the drill hole beneath the overburden or Paleozoic cover will reduce overburden noise, providing physical property data that will enhance the 2D and 3D subsurface images related to geological features.
P02-03-037 Camiro **Detectability of mineral deposits with potential field methods**	This project will expand the modelling criteria of ore deposit types to include data on magnetic susceptibility and comparison to density and geological data to determine ability to detect a buried deposit from the air and ground.	The exploration challenge will be to model expected responses of economic targets, understand the masking effects of the surrounding geological noise and determine the detectability versus deposit relationship of real economic ore bodies.
P02-03-034a Gedex **Onsite geochemistry for locating kimberlites and assessing diamond bearing potential in Ontario**	This project will develop and test a novel prototype pre-concentration device amenable to field conditions. These methods will be optimized for site portability without compromising analytical ability.	The challenge will be to adapt large laboratory technology to a field portable system. In order to maximize the advantages associated with this capacity, sample preparation methods must be modified to allow efficient sample throughput in the environment of a mobile lab, and to support novel analytical concepts.
P02-03-036a Aquapath **Mineral exploration by systematic analysis of ground water upwelling in lakes and rivers**	This project will demonstrate that sampling ground water upwelling in lakes in rivers will identify the chemical signature of Archean basement terrains and zones of mineralization through which ground water has flowed.	The challenge will be to combine modelling of the geometry and geology along with the geochemistry to provide a vector towards mineralization as a cost-effective exploration tool.

Table 31.1. continued

Proposal #, Name and Title	Project Goals	Exploration Challenge Addressed
P02-03-039a Bedrock Research Corp. **Development and evaluation of a tri-axial 3D magnetic survey system**	The project objectives are to evaluate newly developed C++ code and to prove the effectiveness of this methodology both with surface and subsurface data, to discern lithology, structure, geology, thermal and pressure related to remnance not discernable by conventional magnetic data modelling.	The challenges will be to produce tri-axial total field maps at resolutions appropriate to mineral exploration. The effectiveness of this method needs to be proven. The uncertainty of the induced magnetism, especially in areas of structural complexity, could affect the ability to interpret the orientation of the remanent magnetism.
P02-03-038 Gamma Technologies **Development of a new helicopter-borne deep search super conducting survey system sensor technology**	The project goals are to develop a new high power airborne EM system that will be cost effective, have reduced bird wobble, with deep penetration.	The challenge is to develop a sufficiently large, yet light structure EM bird with the geometry that will provide an unprecedented 35 m spacing between the transmitter and receiver antennas. A second challenge will be to provide dat that is usable by standard industry software.
P02-03-043 Bob Lo **New aircraft compensation system for magnetic terrains**	The project goal is to develop compensation software to eliminate the attitude effects of the aircraft in aeromagnetic surveys.	The challenge is to address the magnetic effect due to changing attitude of the aircraft during aeromagnetic surveys. The new compensation system will assist in the accurate interpretation of magnetic data in highly magnetic terrains.

PROGRAM PERFORMANCE

The program approval rate is 51% or 23 proposals out of 45 (Table 31.2). The rejection rate is 44% or 20 of 45 proposals. Two proposals were voluntarily withdrawn from consideration by the proposal proponent.

Consideration of the OMET program performance illustrates that

1. project sponsors and partners see tremendous value in the OMET research program, measured by the financial contribution by project proponents and partners;
2. results from OMET-supported projects are being transferred to, and are being embraced by, the mineral industry to enhance their ability to address Ontario's exploration challenges and to enable Ontario-based service industry to maintain their global competitive advantage.

Indications of the value of the OMET program are summarized in the following testimonials:

- "Noranda Inc. and Falconbridge Limited are pleased to be part of this OMET project and strongly support such initiatives that provide access to new technologies for use in mineral exploration": Mike Peshko (Manager, Remote Sensing, Noranda Inc.) and Patti Tirschmann (Senior Project Geologist, Falconbridge Limited)
- "Thank you for the opportunity to get involved with the OMET program. The demonstration of new technologies within the Province is critical to the future success of the industry. . . . An initial demonstration of Titan 24 on our property has lead to direct tangible deep drilling results.": Ian A. Brodie-Brown, President, Tribute Minerals
- "Over the past year, four companies—Goldcorp, FNX Mining, Falconbridge Ltd., and Tribute—participated in an Ontario Mineral Exploration Technology (OMET) program demonstrating the Titan 24 technology. The results were impressive." *Canadian Mining Journal*, April 2003

Table 31.2. Approved/funded OMET projects as of June 30, 2003.

Proposal		OMET Award	Researcher Cash	Researcher In-kind	Cash Leverage	Total Leverage
P01-02-001	Camiro	$ 56,100	$ 56,100	$ 0	1.0	1.0
P01-02-002	Camiro	$ 358,975	$ 262,040	$ 100,000	0.73	1.01
P01-02-003	Camiro	$ 108,825	$ 168,825	$ 120,000	1.55	2.65
P01-02-007b	Geotech	$ 356,470	$ 207,330	$ 25,000	0.58	0.65
P01-02-008a	GSC	$ 592,000	$ 166,000	$ 489,000	0.28	1.11
P01-02-011a	Ferra Dynamics	$ 74,900	$ 39,000	$ 127,750	0.52	2.23
P01-02-014	Quantec	$ 625,500	$ 190,000	$ 71,500	0.30	0.42
P01-02-016a	Ottawa Univ.	$ 168,040	$ 38,000	$ 104,000	0.20	0.85
P01-02-018	York Univ.	$ 331,500	$ 339,000	$ 175,000	1.02	1.55
P01-02-021	Quantec	$ 431,000	$ 60,000	$ 276,000	0.14	0.78
P01-02-023	Mira Geoscience	$ 529,000	$ 260,000	$ 639,000	0.49	1.70
P02-03-005b	Gedex	$ 800,000	$ 3,314,015	$ 363,000	4.41	4.60
P02-03-025	Barrie	$ 260,460	$ 7,500	$ 420,000	0.03	1.64
P02-03-028	JVX	$ 61,380	$ 38,620	$ 11,600	0.63	0.45
P02-03-031	Mira Geoscience	$ 199,120	$ 97,520	$ 91,230	0.49	0.73
P02-03-037	Camiro	$ 69,844	$ 69,844	$ 0	1.0	1.0
P02-03-034a	Gedex -Sciex	$ 83,500	$ 281,988	$ 121,000	3.38	4.83
P02-03-036a	Aquapath	$ 122,045	$ 149,165	$ 316,570	1.22	3.82
P02-03-039a	Bedrock	$ 85,263	$ 21,452	$ 161,400	0.25	2.14
P02-03-038	Gamma	$ 160,000	$ 85,000	$ 125,000	0.53	1.31
P02-03-043	B. Lo	$ 111,018	$ 37,007	$ 158,650	0.33	1.76
P02-03-022a	Hogg*	$ 82,500	$ 4,000	$ 53,750	0.05	0.70
P02-03-040	Geotech*	$ 142,000	$ 21,500	$ 100,000	0.15	0.86
TOTALS		$ 5,834,400	$ 5,914,691	$ 4,049,450	1.01	1.71

* Conditional Approval

Cumulative awards to date are **$5,834,400**, including all fiscal years and assuming the project goes to completion and conditional projects are approved. The researcher combined cash and in-kind support for the projects totals **$9,964,141**.

Performance Measure 1: Financial leverage.
Target: $.25 from researcher for each OMET $1.00.
Actual: Each OMET $1.00 levers $1.01 researcher cash or $1.71 researchers cash plus in-kind.
Note: This level of financial leverage demonstrates that the OMET projects are well supported by industry, universities and other governments. This performance measure is an indicator of the value perceived in the project by the proponent and the project partners, in as much as they are willing to commit their resources.

Performance Measure 2: Transmission of new knowledge to public.
Target: 1 Transmission per project per year.
Actual: Three projects have been completed to date: P01-02-001, P01-02-014 and P01-02-021. These projects have resulted in industry and universities taking up the new technology to do further research and use the new technology to explore for mineral deposits.

Twelve projects were presented at the Northwest and Northeast Mines and Minerals symposia in Thunder Bay and Haileybury, respectively, during April 2003. Several projects have had on-going sponsor's meetings to give the sponsors an opportunity to provide input into the projects and provide industry direction to the research projects that will help achieve the goals of the proposed new mineral exploration technologies being developed. The next opportunity for researchers to present the results of their work is at the Ontario Exploration and Geoscience Symposium in Toronto in December 2003. Several of the researchers will present papers in the open forum session, as well as presenting data at their display booths.

Performance Measure 3: Uptake of Technology Transfer.
Target: 1 receptor per funded project.
Actual: Approximately 20 different private companies have sponsored and co-funded the OMET funded projects. In some instances, the companies are benefiting from the testing of prototypes of the new technology. This indicates that the private sector strongly supports the technical merit and mineral exploration relevance of these research projects. Uptake of new technology is not an issue. The OMET program has received letters of support for the program from companies stating that they would like to see the program continued.

As an example of the benefit to the Ontario mineral industry, both the Quantec Titan 24 and Quantec Hyperspectral projects have attracted much interest from industry and universities. As a result of the OMET investment, existing technology was advanced and the relevance of the technology was demonstrated more broadly to the industry. As a result, new interest in the technology was created and new business followed. New mineral targets were identified, drilled, and promising diamond drill results remain to be followed up.

CONCLUSIONS

The Ontario Mineral Exploration Technologies program is yielding benefits to the mineral industry, is providing new methods and technologies that are addressing the technical challenges related to exploration in Ontario, has generated new business opportunities, and has played a role in the discovery of new mineral occurrences that are now under active exploration.

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Discover Abitibi Initiative

32. Overview of the Discover Abitibi Greenstone Architecture Project: Subprojects, Goals and Results

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INTRODUCTION

The Discover Abitibi Initiative is a program administered by the Timmins Economic Development Corporation (TEDC) on behalf of Timmins, Kirkland Lake and other municipalities in the Abitibi region. The initiative is funded by the private sector, the federal and provincial governments (respectively Industry Canada through FedNor and the Ontario Ministry of Northern Development and Mines through the Northern Ontario Heritage Fund) and is designed to stimulate mineral exploration in the Ontario portion of the Abitibi greenstone belt. The Discover Abitibi program (www.discoverabitibi.com) has components ranging from various types of geophysical surveys to the "integrated geological study of the Timmins–Kirkland Lake area" upon which we report here.

The Abitibi greenstone belt is relatively mature in terms of the amount and type of mineral exploration and geological mapping undertaken in the recent past. However, given the extensive overburden cover and the fact that most of the near-surface ore deposits have been discovered and exploited, new models are required to increase the effectiveness of exploration. At present, a sampling of exploration problems in the Abitibi greenstone belt is as follows.

Deposit-Scale versus Regional-Scale Interpretation

Detailed knowledge gained from recently completed deposit-scale studies (e.g., Bleeker 1999) require expansion to the regional scale so that features such as structures and the limits of hydrothermal systems can be mapped. For example, deposit-scale studies map the intense part of hydrothermal systems, which then "fade away" to a subtle regional-scale overprint. Identifying the lowest intensity hydrothermal systems reliably will allow future focus on deeply buried mineralization.

Summary of Field Work and Other Activities 2003.
Ontario Geological Survey, Open File Report 6120, p.32-1 to 32-12.

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Stratigraphic Interpretation

At present, there is not enough information available to allow construction of stratigraphic sections and/or to trace stratigraphy at the regional scale. An improved stratigraphic framework is important to mineral exploration since syngenetic mineral deposit types in the Abitibi greenstone belt are known to occur in specific assemblages (e.g., Kidd Creek Mine in the Kidd–Munro assemblage). Identification of major stratigraphic discontinuities will allow identification of possible locations for structurally controlled deposits, such as lode gold and rare metal pegmatites.

Assemblage Architecture

Many characteristics of assemblages within the Abitibi greenstone belt are uncertain. Several geoscience problems will be addressed during this project, such as determining the nature of assemblage contacts (conformable, unconformable, tectonic); determining if assemblages have internal unconformities; identifying intra-assemblage marker units; and characterizing volcanic architecture and/or facies relations. More information regarding assemblage characteristics will provide a better understanding of the regional-scale architecture of many high mineral potential assemblages, such as the Kidd–Munro and Tisdale assemblages.

Lithogeochemistry

In exploration for volcanogenic massive sulphide (VMS) mineralization, does the geochemistry of rhyolites within a given assemblage vary and if so, how? For example, we have unpublished indications that rhyolite geochemistry in the Kamiskotia region varies. Does this indicate two different ages of rhyolites and the need for stratigraphic revisions or, alternatively, that there are hot and cold regions within rhyolite geochemical systems of a single age (e.g., Piercey 2001)? Does iron formation geochemistry vary with proximity to mineralization?

Four-Dimensional Architecture

Four-dimensional architecture of greenstone assemblages is not presently possible in this, the best characterized greenstone belt in Ontario. For example, one cannot erect an assemblage-wide stratigraphy in the Tisdale assemblage or in the Kidd–Munro assemblage. Therefore, one cannot dependably follow any on-strike extension of VMS mineralized units.

Given this background, the Mineral Exploration Research Centre (MERC) in the Department of Earth Sciences at Laurentian University established a consortium involving multiple universities, consultants, and key personnel from the Ontario Geological Survey (OGS) and the Geological Survey of Canada (GSC). This consortium was established to bring together the expert team required to manage and deliver the type of geoscience program needed to address the science gaps identified in the proposal. For legal and administrative reasons, MERC was the agency that bid on, and was awarded the contract for, the "Integrated Geological Study" Request for Proposal issued by the Timmins Economic Development Corporation in March 2003. Laurentian University is the legal authority accountable for the delivery of the project.

Inclusion of university-based researchers and government geoscientists with the consultants on the research consortium will ensure that the comprehensive results of this project would result in additional research and new mapping after its completion. This would occur because the longer term objectives of university-based researchers would be to continue to advance the understanding of concepts and results developed with the Discover Abitibi funding (further enhanced by the possibility of additional add-on funding from sources such as the Natural Sciences and Engineering Research Council of Canada (NSERC)). The involvement of the OGS and GSC geoscientists ensures that the new mapping and research resulting from this project would be integrated into existing and future government mapping programs and that there would a heritage of the personal knowledge about the results and concepts developed during the project that would be freely available to all stakeholders after conclusion of the project. To provide a geological framework for the Discover Abitibi Initiative, the OGS co-planned, with the mineral industry, the OGS core business bedrock mapping projects to help cover geographic areas of interest to the Discover Abitibi Initiative. No Discover Abitibi funding was requested by the OGS to deliver its core business bedrock mapping because that bedrock mapping is part of a existing, multi-year Ontario Government commitment to document the regional geology of the Abitibi greenstone belt.

By using a research consortium with a substantial academic component, TEDC receives the skills of world-class expertise in the form of the Principal Investigators at the lowest possible cost. The low cost is brought about by the researcher's desire to attain their academic goals and the fact that the project brings about important training for MSc students and PhDs employed as Post-Doctoral Fellows (PDF). This arrangement has the additional benefit of potentially bringing matching funds from the NSERC system into play in future.

THE TEAM

The principal investigators listed in Table 32.1 were chosen based on their experience in Archean greenstone belts in general, and their experience with the Abitibi greenstone belt, in particular. The principal investigators are generally university-based researchers, however critical gaps in the project required use of 2 consultants. The individual principal investigators are involved in supervision of individual projects and subprojects as well as being directly involved in Discover Abitibi mapping and research.

Table 32.1. Discover Abitibi Initiative principal investigators.

Team Member	Responsibility	Affiliation
J.A. Ayer	Spokesperson for project team with industry, Timmins Economic Development Corp. Abitibi regional geology, stratigraphy and gold deposits	Precambrian Geoscience Section, OGS
P.C. Thurston	Spokesperson for Laurentian University, greenstone belt stratigraphy, and VMS projects	MERC, Laurentian University
B. Dubé	Gold deposit geology in the Superior Province	Geological Survey of Canada – Québec
A.D. Fowler	Volcanic textures, gold deposits	University of Ottawa
H. Gibson	VMS deposits, volcanology in the Superior Province	MERC, Laurentian University
G. Hudak	VMS deposits stratigraphy and alteration systems	University of Wisconsin Oshkosh
B. Lafrance	Gold deposits and structural geology	MERC, Laurentian University
C.M. Lesher	komatiites, Cu-Ni-PGE deposits	MERC, Laurentian University
S.J. Piercey	Geochemistry, volcanic stratigraphy and VMS deposits	MERC, Laurentian University
L. Reed	Potential field geophysics	Consultant
P.H. Thompson	Metamorphic petrology	Consultant

PROJECTS AND SUBPROJECTS

The principal investigators developed the individual projects and subprojects and are involved in both the execution and supervision of the individual components listed in Table 32.2. Given the necessity of doing high-level investigations immediately upon start-up, the Greenstone Architecture project is staffed by Post-Doctoral fellows (PDF) recruited by Laurentian University based upon international advertising and interviewing. All PDFs have extensive experience in Precambrian greenstone belts or terranes directly relevant to the project. Table 32.2 lists the general terms of reference for each project, the PDF doing the work (shown in bold type) and the supervisory principal investigators. Note that 2 subprojects are utilizing MSc students.

Table 32.2. Discover Abitibi Greenstone Architecture Project details.

Subproject	**Area of Study**	**Investigator** and Supervisor(s)
Kamiskotia and Kidd–Munro (Kidd Creek) areas	2 years mapping and researching the geological, structural, and stratigraphic relationships associated with VMS mineralization and alteration	**Ben Hathway,** Phil Thurston, George Hudak, Harold Gibson
Blake River, eastern Kidd–Munro and Tisdale assemblages	2 years work in corridors in the eastern part of the area in the Kidd–Munro, Blake River, and Tisdale assemblages	**Shirley Péloquin,** Steve Piercey, Harold Gibson
Genex deposit	MSc thesis study on controls on the Genex VMS deposit in the Kamiskotia area	**Stephanie Hocker,** Harold Gibson, Phil Thurston
Tisdale and Kidd–Munro assemblages	Affiliated OGS project to complement the Discover Abitibi VMS project by focussing on Ni-Cu-(PGE) mineralization in the Shaw Dome south of Timmins	**Michel Houlé,** Michael Lesher, John Ayer
Timmins Gold Project	1) North of the Hollinger–Coniaurium trend to south of the Dome–Buffalo Ankerite occurrences, 2) north of the Hoyle Pond–Owl Creek trend to south of the Pamour Mine also encompassing the PDDZ in this area	**Roger Bateman,** John Ayer, Benoit Dubé
Kirkland Lake Gold Project	Camp-scale detailed mapping and deposit studies focussed in the Kirkland Lake area and Gauthier Township areas, from north of the Timiskaming unconformity, encompassing gold deposits to south of the Larder–Cadillac deformation zone (LCDZ)	**Vladimir Ispolatov,** Bruno Lafrance, Benoit Dubé
Intrusion Subproject (gold)	MSc thesis study on role of porphyry intrusions associated with gold mineralization	**Peter MacDonald,** Steve Piercey
Intrusion Subproject (base metals)	Role of subvolcanic intrusions in base-metal mineralization	**Steve Piercey**
Metamorphic Subproject	Timmins to Kirkland Lake area	**Peter H. Thompson,** John Ayer

Methods

STRATIGRAPHIC COMPONENT

Development of detailed and regional stratigraphy provides the underpinning for understanding geological features related to mineralization, such as volcanologic facies variation, structural style, alteration patterns, metamorphic patterns, etc. Therefore, in this project, we expand outward from well-characterized syngenetic deposits through detailed bedrock mapping (1:5000 to 1:20 000) of key corridors within critical assemblages and integrating this data with existing regional and detailed mapping. A later component of the project will attempt to apply the detailed stratigraphic revisions on a regional scale. The stratigraphic mapping will be the first step in the volcanogenic massive sulphides (VMS)-related work. The stratigraphic studies will be integrated with the subprojects described below and will include the following components:

1. construction of stratigraphic sections mainly based on lithology, volcanic and sedimentary structures and texture
2. refinement of the sections through integration with petrographic and geochemical data to distinguish magma clans and tectonic settings (e.g., Barrie, Hannington and Bleeker 1999; Tomlinson et al. 1998)
3. interpretation of the above within the context of volcanic and sedimentary facies to better identify potential regional-scale marker units
4. identification of texturally and/or geophysically distinctive marker units within the sections (e.g., variolitic horizons, graphitic argillite, banded iron formations)
5. expansion of stratigraphy outward to a regional scale through integrated tracing of texturally, geochemically and/or geophysically distinctive marker units. This will involve expansion of both regional-scale (e.g., Ayer et al. 2002) and district-scale (e.g., Barrie and Corfu 1998; Bleeker 1999) stratigraphic models
6. integration of detailed and regional stratigraphic sections with geochronologic data to identify gaps in geochronologic coverage for further age determinations
7. integration of stratigraphic models with structural investigations to identify possible repetition of stratigraphy, folds, faults, etc. (e.g., Heather 1998)

GEOPHYSICS

Geophysical interpretation is a crucial component of the project due to the thick overburden and scattered nature of bedrock exposures in the Abitibi greenstone belt. All government airborne geophysical data, magnetic electromagnetic and gravity data have been made available to the project as an in-kind donation by the Ontario Geological Survey. The Ontario Geological Survey has provided routine plots, such as shaded relief total field magnetic data, second vertical derivative of total field magnetic data and a variety of other plots.

The geophysical consultant to the project will provide customized interpretation and plots, such as three-dimensional inversions of magnetic data and two-dimensional inversions of the various electromagnetic surveys in subproject areas. Existing physical rock property data on selected samples in the Kirkland Lake and Matheson areas (Deschamps 2000) will be used during the inversions, as will new magnetic susceptibility and specific gravity measurements from the greater than 1000 samples collected for lithogeochemistry from the field-based subprojects.

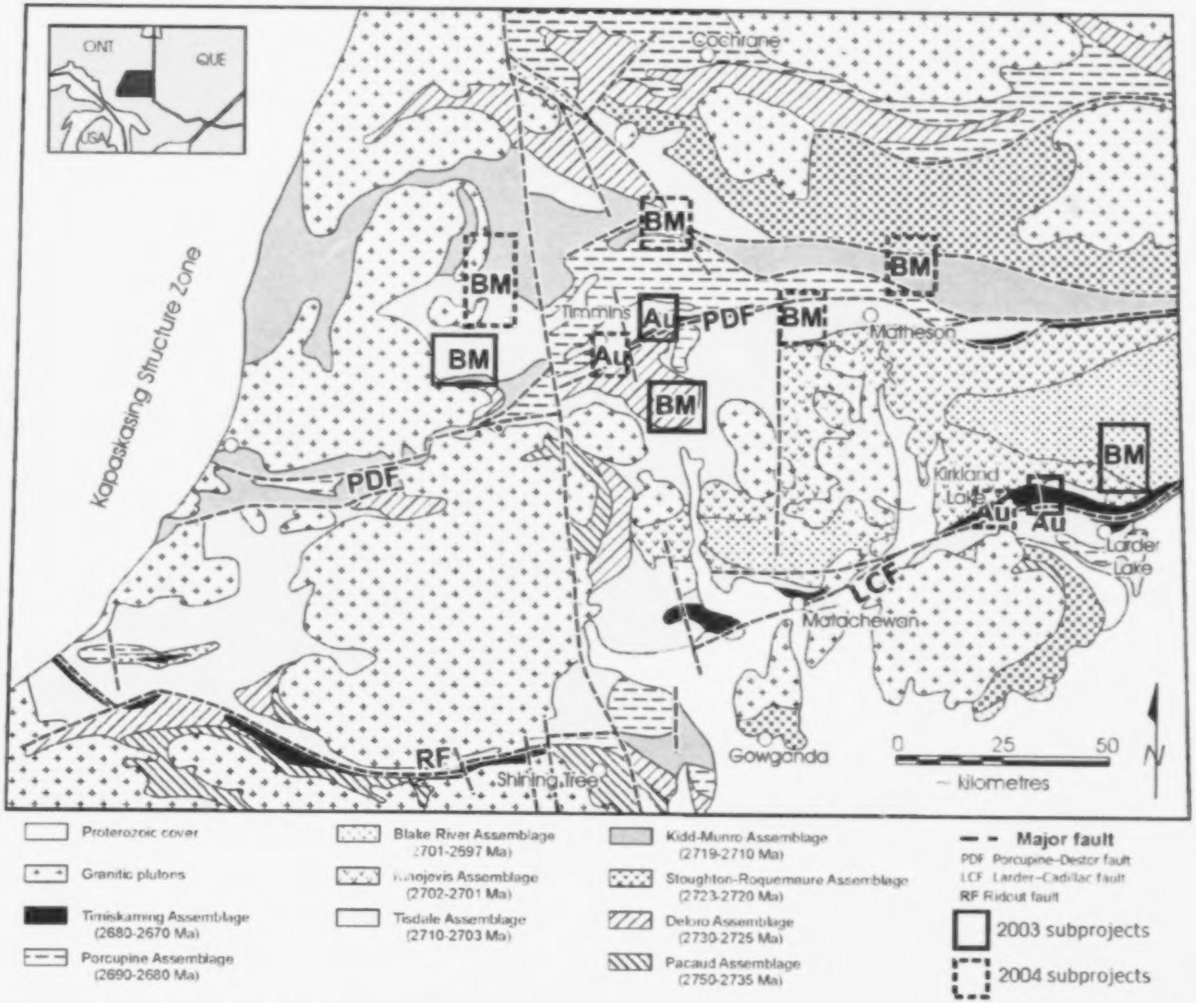
ONT
QUE
USA
Cochrane
Timmins
Matheson
Kirkland Lake
Larder Lake
Matachewan
Gowganda
Shining Tree
Kapuskasing Structure Zone
PDF
LCF
RF
BM
Au
0
25
50
~ kilometres
N
Proterozoic cover
Granitic plutons
Timiskaming Assemblage (2680-2670 Ma)
Porcupine Assemblage (2690-2680 Ma)
Blake River Assemblage (2701-2697 Ma)
Kinojevis Assemblage (2702-2701 Ma)
Tisdale Assemblage (2710-2703 Ma)
Kidd-Munro Assemblage (2719-2710 Ma)
Stoughton-Roquemaure Assemblage (2723-2720 Ma)
Deloro Assemblage (2730-2725 Ma)
Pacaud Assemblage (2750-2735 Ma)
Major fault
PDF Porcupine–Destor fault
LCF Larder–Cadillac fault
RF Ridout fault
2003 subprojects
2004 subprojects

Figure 32.1. Map showing the location of the Discover Abitibi Greenstone Architecture subprojects. Lithotectonic assemblage *after* Ayer et al. (2002). Solid boxes show the approximate locations of subprojects in 2003; dashed boxes show the location of subprojects in 2004. Boxes labelled BM refer to base metal subprojects; Au refers to gold subprojects.

Volcanogenic Massive Sulphide and Gold Subprojects

VOLCANOGENIC MASSIVE SULPHIDE DEPOSITS

The bedrock mapping and research for these subprojects are concentrated in corridors spanning the 3 assemblages that are most favourable for base metals and synvolcanic gold mineralization: the Kidd–Munro, Tisdale and Blake River assemblages (Figure 32.1). All corridors will be mapped and detailed mapping, diamond-drilling and geophysics from mining companies will be compiled at an appropriate scale. The subprojects will generate maps (1:20 000 to 1:5000 scales) with detailed lithologic, structural, facies and alteration information. These mapping-based controls will be constrained by new U/Pb geochronological data augmenting existing radiometric ages. A lithogeochemical database, constructed by incorporating new geochemical data with pre-existing data of acceptable quality, will be used to characterize all major lithologic units. This will also constrain the stratigraphy and help to better define major structures. Lithogeochemistry, petrography and mineral chemistry will also be used to help define the nature and intensity of hydrothermal alteration and metamorphism.

Once the stratigraphy has been established using lithological and facies mapping, geochemistry, structural controls and new geochronology in the vicinity of all of the above areas, stratigraphic and structural sections will be constructed. The stratigraphic sections will be constrained at depth by the available physical property measurements (Deschamps 2000) and the above proposed inversions of airborne magnetic, electromagnetic, surface gravity and reflection seismic data where available.

NICKEL-COPPER-PLATINUM GROUP ELEMENT DEPOSITS

An affiliated OGS project has been designed to complement the Discover Abitibi Greenstone Architecture project. It will be focussed on nickel-copper-platinum group element (PGE) mineralization in the Shaw Dome area south of Timmins, in the vicinity of the Langmuir, Hart, McWatters, and Redstone deposits (Houlé, Lesher and Hall, this volume). Nickel-copper-(PGE) sulphide mineralization associated with komatiitic rocks (komatiites and komatiitic basalts) in Archean and Proterozoic greenstone belts are an important part of the broader category of magmatic Ni-Cu-PGE mineralization. The goals of this project are three-fold: 1) to evaluate the subvolcanic–volcanic architecture of the ultramafic rocks of the Shaw Dome; 2) to evaluate the Ni-Cu-(PGE) mineral potential of the komatiitic rocks; and 3) to better understand the stratigraphic and structural configuration of the ultramafic rocks in the context of the Shaw Dome. Geophysical and diamond-drill hole data are being used to aid in the extrapolation of geological contacts across the many large areas obscured by overburden.

GOLD DEPOSITS

The goal of the gold subprojects will be to identify and characterize the key geological parameters controlling the formation and distribution of gold deposits at the district scale in order to help design exploration strategies. Key parameters that will be investigated include outcrop-scale structures, lithologic units, intrusions and alteration facies that control the distribution of the mineralization and/or host the mineralization. The project will also better delineate the Timiskaming unconformity and its role in the localization of gold mineralization since there are clear empirical and spatial relationships between the location of large gold deposits and the unconformity (e.g., Dome Mine; *see also* Dubé, Williamson and Malo 2003). At a regional scale, we will address important knowledge gaps concerning the tectonic evolution of the southern Abitibi greenstone belt, focussing on the main fault zones that disrupt the stratigraphy and localize gold deposits. Mapping and sampling will be carried out in regions that straddle the Porcupine-Destor deformation zone (PDDZ) and the Larder–Cadillac deformation zone (LCDZ) (*see* Figure 32.1) by including the highly deformed fault zone rocks and the less deformed rocks proximal to the fault zones. In this way, we will be able to define the strain gradient and identify preserved structures that may be related to an early stage of rifting (Ayer et al. 2002) that could have accompanied early generations of gold mineralization. Detailed kinematic and structural mapping are required to establish the structural evolution of the fault zones, including successive reactivation events. The role of the major fault zones in disrupting stratigraphy, creating permeable zones for gold mineralization and the relative and absolute age constraints of the gold mineralizing event (e.g., Connolly and Gosgrove 1999; Hobbs et al. 2000) are key parameters for our investigation. The spatial and structural relationships between the PDDZ, the Dome fault, and the Hollinger fault, and between the LCDZ and the Kirkland Lake "main break" (*see* Figure 32.1), will be investigated as these faults clearly controlled the distribution of the gold mineralization.

SUBVOLCANIC INTRUSIONS, GOLD AND BASE METALS

This subproject is designed to examine subvolcanic intrusions long considered to have a possible genetic relationship with both gold (Mason and Melnik 1986; Burrows and Spooner 1986) and base metal deposits (e.g., Barrie, Hannington and Bleeker 1999). The gold-related porphyry intrusions are the subject of an MSc investigation (MacDonald and Piercey, this volume). The base metal component of the problem will be investigated by S.J. Piercey with work on intrusions such as those in the area described by Péloquin and Piercey (Péloquin and Piercey, this volume) and the Kamiskotia area (Hathway and Thurston, this volume). The project will involve mapping, geochemistry, petrography and geochronology to better understand the lithological distribution, petrogenesis, alteration characteristics, linkages with mineralization and ages of these intrusions. The recent work in the Cordillera by Piercey (2001) is comparable to that proposed here.

METAMORPHIC SUBPROJECT

Metamorphic petrology has been under-utilized in identifying original rock types, stratigraphy and in mapping haloes related to hydrothermal alteration. Definition of the distribution and intensity of "background" metamorphic grade is used to define the limits and nature of alteration associated with syn- and post-metamorphic, shear zone-hosted gold mineralization (e.g., Thompson 2002). Metamorphic petrology will also help to identify the transition from proximal, deposit-related VMS alteration (Hannington et al. 2003) to normal regional "background" assemblages. Metamorphic mineral assemblages and textures will be used to constrain the timing, duration and depth of deformation and plutonism, which are important factors in the formation of many ore deposits.

SUBPROJECT DETAILS

Table 32.2 provides details on the staffing and supervision of each of the subprojects begun this year. Not listed in Table 32.2 are the geophysical and stratigraphic components of the program in that they are integral to each of the projects and subprojects listed below.

PRODUCTS

All field data collection is done digitally and maps prepared using ESRI® ArcView® 8.3. Products will be released through the Ontario Geological Survey publications release process. The stream of products envisaged is

1. articles for *Summary of Field Work and Other Activities* in 2003 and 2004 for all projects for which field work was done in 2003 and 2004
2. release of results from both years of field investigation will be through industry workshops with accompanying posters and published maps
3. final project reports, published as OGS Open File Reports, complete with digital files of all data collected

RESULTS

In the sections above, we described the general goals of the subprojects. In the paragraphs below, we provide an overview of results obtained thus far in our investigations.

Greenstone-Belt Scale

Nomenclature for supracrustal rocks has evolved rapidly in the Abitibi greenstone belt. In the 1980s and 1990s, lithotectonic nomenclature was employed based on the notion that the boundaries between most assemblages were tectonic and that assemblages may well represent separate allochthonous accreted terranes (Jackson and Fyon 1991). The presence of isotopic inheritance in the Abitibi greenstone belt (Ayer et al. 2002) and elsewhere in the Superior Province (Thurston 2002) leads to the realization that stratigraphic nomenclature is quite appropriate. Accordingly, both styles of nomenclature for supracrustal units appear in Discover Abitibi articles in this volume.

At the scale of the Abitibi greenstone belt, we have integrated recently completed geochronological data, some of which is an in-kind donation from industry partners (e.g., Ayer, Barr et al., this volume), into a revised table of lithotectonic assemblages (Table 32.3). We anticipate that details of this table will change through our investigations over the next 2 years.

Volcanogenic Massive Sulphide Mineralization Subprojects

The subprojects investigating VMS mineralization differ somewhat from geological survey mapping in that there is emphasis on volcanic facies variation, alteration and regional-scale stratigraphic and structural variation. When this emphasis is combined with the associated lithogeochemical compilation, an improved view of the relationship between rhyolite geochemistry and mineralization will be realized.

The Kamiskotia subproject (Hathway and Thurston, this volume) was designed to characterize a largely rhyolitic unit lying north of and probably stratigraphically above metavolcanic rocks in Carscallen Township, which is similar in age to the Kidd–Munro assemblage, and west of a rhyolitic unit in Jessup Township, which is similar in age to the Tisdale assemblage. The authors have developed a stratigraphic section through a dominantly rhyolitic sequence in Turnbull, Godfrey, Bristol and Carscallen townships with 2 major units differing in phenocryst types, style of volcanism and volcanic facies. Recent advances in rhyolite volcanology have allowed use of normal and reverse grading to obtain numerous top

Table 32.3. Summary of southern Abitibi greenstone belt supracrustal assemblage names, ages, basal contacts, rock types and chemical affinities.

Assemblage Name (Age in Ma)	Basal Contact Relationships	Dominant Rock Types	Volcanic Chemical Affinity
Timiskaming (2680-2670)	Unconformable	Conglomerate, sandstone, mafic to intermediate volcanic and iron formation	Alkalic to shoshonitic
Porcupine (2690-2680)	Unconformable	Turbidite, felsic to intermediate volcanic, conglomerate and iron formation	Calc-alkalic to shoshonitic
Blake River (2701-2697)	Conformable to disconformable	Mafic to felsic volcanic	Tholeiitic and calc-alkalic
Kinojevis (2702-2701)	Conformable	Mafic and minor felsic volcanic	Tholeiitic
Tisdale (2710-2703)	Conformable to disconformable	Ultramafic, mafic, intermediate to felsic volcanic and iron formation	Komatiitic, tholeiitic and calc-alkalic
Kidd-Munro (2719-2711)	Conformable to disconformable	Ultramafic, mafic, intermediate and felsic volcanic and iron formation	Komatiitic, tholeiitic and calc-alkalic
Stoughton-Roquemaure (2723-2720)	Conformable to disconformable	Ultramafic, mafic, intermediate and felsic volcanic	Komatiitic, tholeiitic & calc-alkalic
Deloro (2730-2724)	Disconformable	Mafic, intermediate and felsic volcanic and iron formation	Tholeiitic and calc-alkalic
Pacaud (2750-2735)	Unknown	Ultramafic, mafic and felsic volcanic	Komatiitic, tholeiitic and calc-alkalic

determinations in the sequence, permitting postulation of a regional-scale antiform. Therefore, the project has permitted a better understanding of the stratigraphic context of the Genex and Canadian Jamieson VMS deposits. Geochronological sampling will permit refinement of the stratigraphic context of the major units and establishment of the age of the Kamiskotia area VMS deposits.

The subproject examining the Genex and Canadian Jamieson VMS deposits has improved our knowledge of stratigraphic controls and alteration at both deposits (Hocker et al., this volume). The authors have clearly placed the deposits in the upper part of the rhyolitic succession. Some mineralization is associated with a critical contact in a mafic metavolcanic unit, but most is associated with rhyolitic, pyroclastic and epiclastic rocks. Alteration mapping will provide tools for future evaluation of other mineralization.

The Blake River subproject (Péloquin and Piercey, this volume) was designed to assess the mineralization potential of the Blake River Group on the Ontario side of the interprovincial border. The field work has identified proximal felsic and intermediate metavolcanic rocks, such as dome collapse breccias, lobe and breccia rhyolite flows with synvolcanic dikes and alteration corridors. The alteration and facies mapping has disclosed areas of alteration not previously known.

Gold Projects

The Timmins area gold subproject (Bateman, Ayer and Dubé, this volume) is commencing the process of integration of deposit-scale knowledge of the Timmins camp gold deposits into a regional framework. Work has begun at the eastern end of the camp in the vicinity of the Hoyle Pond and Pamour gold deposits. The gold mineralization is largely hosted by Timiskaming and Tisdale assemblage units. Six generations of structures have been identified. Significant mineralization is within D_2 broad folds on the overturned limb reactivated during D_4. This interpretation has resulted in recommendations for further exploration.

The Kirkland Lake area gold subproject (Ispolatov, Lafrance and Dubé, this volume) will integrate deposit-scale knowledge of the Kirkland Lake camp gold deposits into a regional framework. Work has begun in the eastern part of the camp in Gauthier Township in the vicinity of the Anoki, McBean and Upper Canada mines. The mineralization occurs in Timiskaming assemblage and Tisdale assemblage (Larder Lake Group) metavolcanic rocks and is closely associated with the Larder–Cadillac and the Upper Canada deformation zones. Five generations of structures have been identified and the gold mineralization is interpreted to be coeval with S_2 and the development of the deformation zones.

Intrusion Subproject

The intrusion subproject has 2 components: 1) identification of the role and characteristics of "porphyry" intrusions spatially and perhaps genetically associated with Timmins area gold deposits; and 2) identification of the role of subvolcanic mafic to felsic intrusions in VMS mineralization in the Abitibi greenstone belt. The former is reported on by MacDonald and Piercey (MacDonald and Piercey, this volume) and the latter component will be the object of next year's program by S.J. Piercey. MacDonald and Piercey (MacDonald and Piercey, this volume) subdivide the Timmins area porphyry bodies into 2 trends: 1) the Vedron–Paymaster–Dome trend and 2) the Hollinger–McIntyre–Coniaurium trend. They describe contact relations of the porphyritic and country rock and a variable alteration mineralogy. Most gold mineralization is associated with intense sericite and moderate ankerite alteration.

Metamorphic Subproject

This report integrates new metamorphic data obtained from a test area (Thompson, this volume) in the Watabeag Lake area (Sheraton, Timmins, McEvay, Michie and Nordica townships) using the geological setting developed by Vaillancourt (2001) as an example of the work to be done on a much larger scale during the two-year mandate of the Discover Abitibi Initiative. The method identifies areas of anomalously low or anomalously high metamorphic grade as well as areas with closely spaced metamorphic isograds, all signs of anomalous fluid flow possibly related to mineralization. The subproject has identified an area of metallogenic interest in Sheraton Township.

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33. Discover Abitibi. New Geochronological Results from the Timmins Area: Implications for the Timing of Late-Tectonic Stratigraphy, Magmatism and Gold Mineralization

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INTRODUCTION

Ongoing tectono-stratigraphic evaluation of the southern Abitibi greenstone belt (SAGB) has utilized U/Pb geochronological data and the results of a regional-scale geological compilation to subdivide the supracrustal rocks into 9 autochthonous stratigraphic assemblages (Ayer, Amelin et al. 2002; Ayer, Ketchum and Trowell 2002). The 2 youngest units are identified as the Porcupine and Timiskaming assemblages and are considered to be late tectonic in the evolution of the SAGB. They are predominantly clastic units unconformably deposited on older volcanic assemblages and are relatively close to the timing of epigenetic gold mineralization in the SAGB.

GEOCHRONOLOGY

Methods

This report provides a synthesis and update on new stratigraphic and gold mineralization geochronological data that represents collaboration between the Ontario Geological Survey (OGS) and the Porcupine Joint Venture (PJV) in the Timmins area. This research was focussed on an improved understanding of the distribution and timing of the late-tectonic stratigraphy, intrusions, and their spatial and temporal relationships to epigenetic gold mineralization. Funding for 2 years of new metallogenic research has been provided by the Discover Abitibi Initiative (Ayer, Thurston et al., this volume). Mapping and research, including new geochronological investigations, began this summer and will allow comprehensive evaluation of a number of aspects associated with gold mineralization in the Timmins and Kirkland Lake areas (Bateman et al., this volume; Ispolatov, Lafrance and Dubé, this volume; MacDonald and Piercey, this volume).

Summary of Field Work and Other Activities 2003,
Ontario Geological Survey, Open File Report 6120, p.33-1 to 33-11.

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The new stratigraphic dating presented in this report has been sponsored by the OGS and the PJV using U/Pb analyses conducted at the Jack Satterly Geochronology Laboratory (formerly at the Royal Ontario Museum) and the Geological Survey of Canada Laboratory. Processing involved standard rock crushing, mineral separation, zircon selection, zircon dissolution, and thermal ionization mass spectrometry techniques. Zircons were air abraded to reduce discordance and were analyzed without chemical isolation of U and Pb due to their small size (almost all <3 µg). The vast majority of analyses represent single zircon crystals. Age uncertainties cited in the text and shown in concordia plots are given at the 95% confidence level.

The new ages presented herein for gold mineralization events in the Timmins area were sponsored by the PJV. These analyses included Re/Os ages of fine-grained molybdenite using negative thermal ionization mass spectrometry techniques at the University of Alberta. The procedures used are presented in detail by Selby and Creaser (2001a, 2001b). Additional geochronology was performed using U/Pb isotopic analysis of monazite crystals using the SHRIMP II at the Centre for Global Metallogeny in Perth, Australia. Monazite grains were identified in thin section using an E3 environmental scanning electron microscope (SEM). Plugs containing phosphate grains were drilled out and mounted in epoxy for *in situ* analysis. The U/Pb French standard (split of MAD-1; Foster et al. 2000) was on a separate mounts that was gold-coated with the sample mounts. Analyses were performed on SHRIMP II, following the methodologies of Foster et al. (2000). The primary O_2^- ion current was ≈0.25 nA on a spot <10 µm diameter. Where sequential measurements were taken on single spots, Pb–Th and Pb–U element ratios were not recalibrated for the second analyses: concordance for the second spot is assumed to be that same as for the first.

Porcupine Assemblage

Born (1995) classified the turbiditic metasedimentary rocks of the Porcupine assemblage into 3 different formations: 1) the Whitney Formation lying south of the Porcupine–Destor fault; 2) the Beatty Formation, which conformably overlies calc-alkalic metavolcanic rocks of the Krist Formation in Tisdale Township; and 3) the Hoyle Formation, an extensive unit lying north of Timmins. Based on recent geochronology results (Ayer, Ketchum and Trowell 2002), we now interpret that the Krist Formation and all of the above turbidite formations to be units within the Porcupine assemblage.

The Krist Formation occurs locally at the base of the Porcupine assemblage. It is a calc-alkalic felsic fragmental unit disconformably underlain by graphitic argillite and tholeiitic mafic volcanic rocks of the Tisdale assemblage (ca. 2707 Ma). Recent geochronological results (Ayer, Ketchum and Trowell 2002) revealed an age of 2687.3±1.6 Ma for a felsic lapilli tuff from the nose of the Porcupine syncline (Figure 33.1: location 1) and 2687.5±1.3 Ma for felsic tuff in the core of the Kayorum syncline (*see* Figure 33.1: location 2). These data indicated that the previous Corfu, Jackson and Sutcliffe (1991) age of 2698 Ma for the sample at location 1 reflected an inherited zircon component in the Krist and was not the depositional age. These new data also indicate that conformably overlying turbidites of the Beatty Formation were deposited shortly after ca. 2687 Ma. This interpretation is supported by a maximum depositional age of 2685±6 Ma from turbidites from the Hoyle Formation in Kidd Township (Bleeker, Parrish and Sager-Kinsman 1999).

Our new geochronological results indicate that the Krist Formation is more extensive than was previously recognized as felsic volcanic rocks, with similar ages, have now been identified south of the Porcupine–Destor fault (PDF) (*see* Figure 33.1). A sample of quartz phyric lapilli tuff from diamond-drill core in Whitney Township (DDH TI-3488, *see* Figure 33.1: location 3) was previously reported as part of the Deloro assemblage (Ayer et al. 1997). The initial geochronology provided concordant $^{207}Pb/^{206}Pb$ ages of 2697.7±4.2 Ma, 2725.0±2.7 Ma, and 2725.5±3.6 Ma for 3 relatively large single grains. The initial

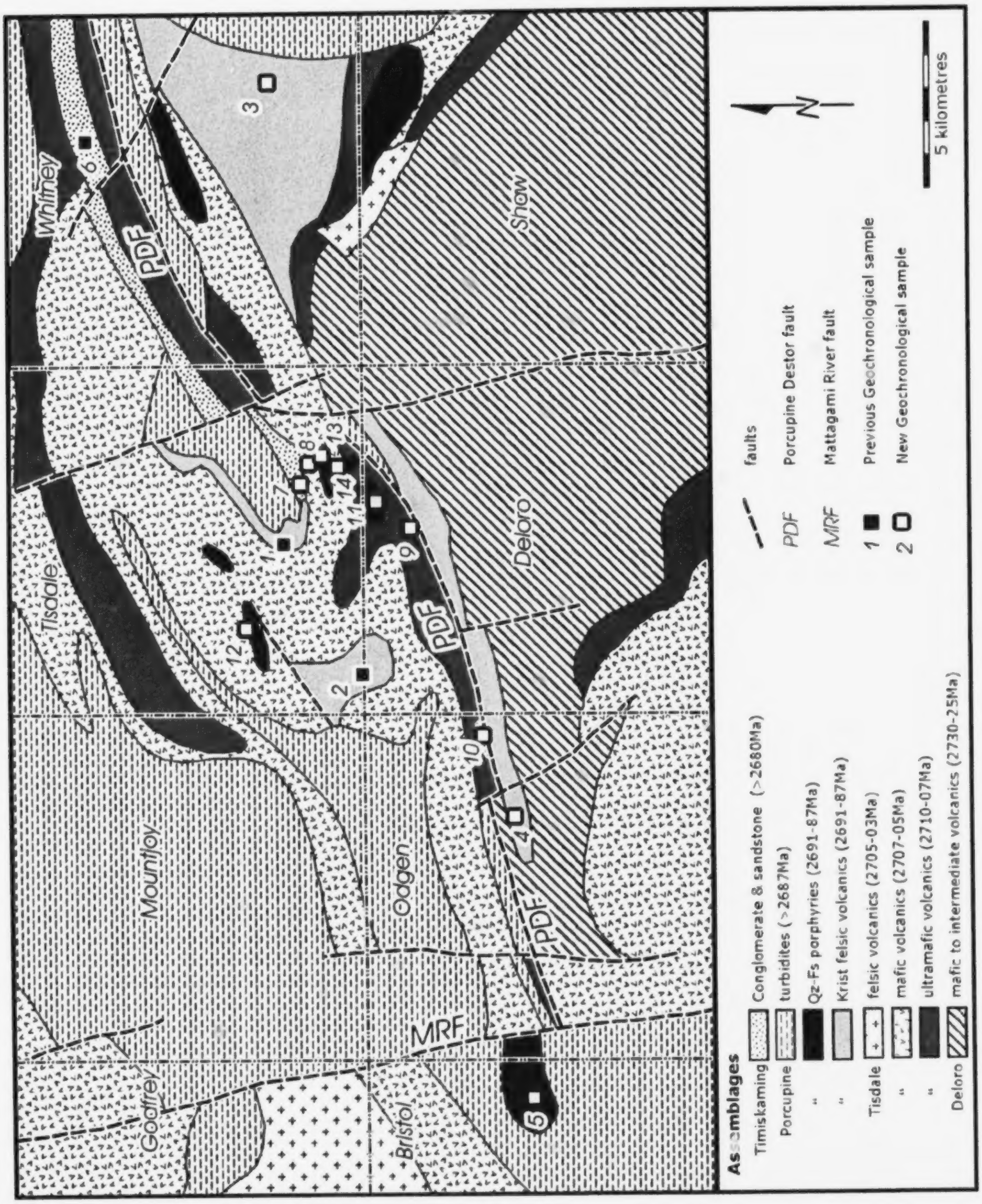

Whitney
Tisdale
Mountjoy
Godfrey
Bristol
Odgen
Deloro
Shaw
PDF
MRF
1
2
3
4
5
6
7
8
9
10
11
12
13
14
5 kilometres
Assemblages
Timiskaming
Conglomerate & sandstone (>2680Ma)
Porcupine
turbidites (>2687Ma)
Qz-Fs porphyries (2691-87Ma)
Krist felsic volcanics (2691-87Ma)
Tisdale
felsic volcanics (2705-03Ma)
mafic volcanics (2707-05Ma)
ultramafic volcanics (2710-07Ma)
Deloro
mafic to intermediate volcanics (2730-25Ma)
faults
PDF Porcupine Destor fault
MRF Mattagami River fault
1 Previous Geochronological sample
2 New Geochronological sample

Figure 33.1. General geology of the Timmins area with assemblages and geochronological sample locations.

interpretation of the age of this sample as 2725 Ma discounted the youngest zircon because it was thought to be a contaminant grain. This is because evidence for widespread zircon inheritance throughout the SAGB was not recognized at the time of the initial interpretation. Based on our more recent findings (Ayer, Ketchum and Trowell 2002), we decided to further investigate the age of this sample by extracting 4 single zircons from a population of smaller grains than were initially sampled. Three of these grains have an average $^{207}Pb/^{206}Pb$ age of 2691.5±1.5 Ma (Figure 33.2A). This age is now interpreted to be the primary crystallization age of the unit and, thus, it is considered to be part of the Krist Formation. The fourth single grain is concordant at 2720.1±2.2 Ma, which, in combination with the earlier results, indicates the unit contains inherited zircons with ages ranging from 2725 to 2698 Ma.

A sample of foliated quartz-feldspar porphyritic felsic rock in the core of an east-trending anticline in northern Ogden Township (Sample 02JAA-9, *see* Figure 33.1: location 4) was also selected for geochronology. Abundant colourless, euhedral faceted prisms (2:1 to 4:1) characterize the zircon population. Outer portions of grains, although resembling metamorphic overgrowths, are highly uniform and are likely indicative of a late igneous growth phase. Three strongly abraded single grains have an average $^{207}Pb/^{206}Pb$ age of 2685.1±1.3 Ma (72% probability of fit (p.o.f.)) (Figure 33.2B) and is interpreted as the primary age of the unit. This age suggests the unit is part of the Krist Formation.

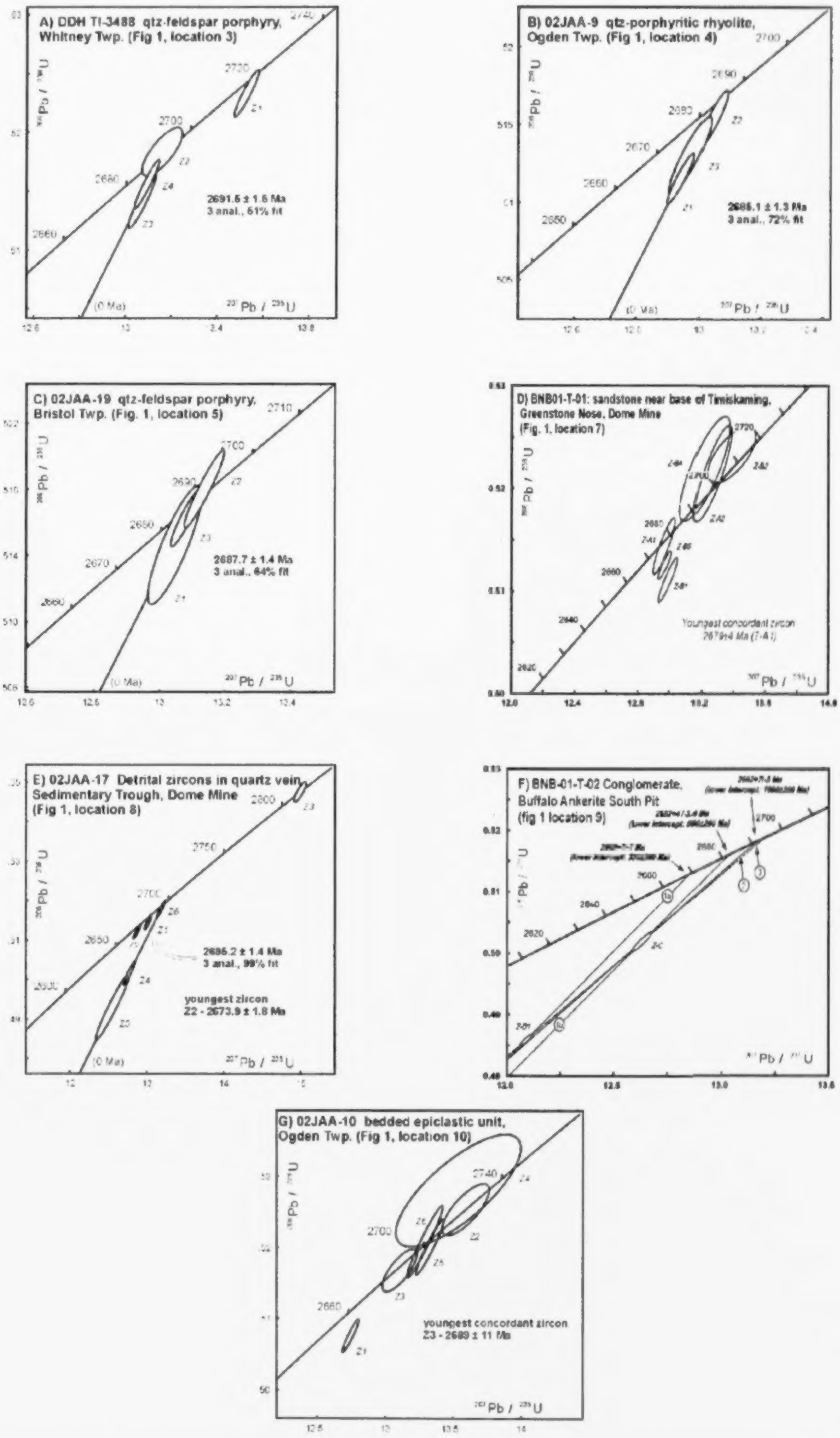
Porphyry Intrusions

The revised younger age for the Porcupine assemblage also has significant metallogenic implications because it indicates that felsic volcanism of the Krist Formation is coeval with the calc-alkalic felsic porphyries in Timmins (ranging in age from 2691±3 Ma to 2688±2 Ma: Corfu et al. 1989). These porphyries have a close spatial association to gold mineralization (MacDonald and Piercey, this volume) and have been interpreted to be associated with an early "porphyry style" gold mineralization event in the Timmins camp (Gray and Hutchinson 2001).

To test the extent of this felsic intrusive event associated with gold mineralization, we sampled a quartz-feldspar porphyry in diamond-drill core (Cameco Corp. DDH BRS-01-07, 664-665.5 m) associated with early gold mineralization in Bristol Township (i.e., gold mineralization in disseminated sulphide minerals with high Ag–Au ratios). The sample is from a location west of the Matagami River fault (*see* Figure 33.1: location 5). It consists of weakly sericitized quartz-feldspar porphyry that intrudes volcaniclastic to epiclastic rocks tentatively correlated with the Porcupine assemblage. Colourless, four-sided, 2:1 euhedral prisms comprise the main zircon population. A few grains have a longer aspect ratio (3:1 to 4:1). Cracks and fluid inclusions are relatively common. The best quality small prisms were abraded, and 3 multigrain fractions are concordant with an average $^{207}Pb/^{206}Pb$ age of 2687.7±1.4 Ma (64% p.o.f.) (Figure 33.2C). This is interpreted as the age of the quartz-feldspar porphyry and demonstrates a time of emplacement similar to that of the Krist Formation.

Timiskaming Assemblage

The Timiskaming assemblage constitutes the youngest supracrustal assemblage in the SAGB. In the Timmins area, it is confined to a narrow east-trending unit of conglomerates and sandstone overlying the Tisdale and Porcupine assemblages. An angular unconformity occurs along the north contact of the Timiskaming assemblage and it is truncated by the PDF to the south. Born (1995) subdivided the Timiskaming assemblage in this area into the lowermost Dome Formation, consisting of alluvial sediments grading upward into proximal and mid-fan turbidites, which are overlain by the Three Nations Formation grading upward from alluvial to fluvial to shelf-facies sandstones. Corfu, Jackson and Sutcliffe (1991) analyzed a sandstone from the Dome Formation (*see* Figure 33.1: location 6) with the youngest



A) DDH TI-3488 qtz-feldspar porphyry, Whitney Twp. (Fig 1, location 3)

B) 02JAA-9 qtz-porphyritic rhyolite, Ogden Twp. (Fig 1, location 4)

C) 02JAA-19 qtz-feldspar porphyry, Bristol Twp. (Fig. 1, location 5)

D) BNB01-T-01: sandstone near base of Timiskaming, Greenstone Nose, Dome Mine (Fig. 1, location 7)

E) 02JAA-17 Detrital zircons in quartz vein, Sedimentary Trough, Dome Mine (Fig 1, location 8)

F) BNB-01-T-02 Conglomerate, Buffalo Ankerite South Pit (fig 1 location 9)

G) 02JAA-10 bedded epiclastic unit, Ogden Twp. (Fig 1, location 10)

2691.5 ± 1.5 Ma
3 anal., 51% fit
2686.1 ± 1.3 Ma
3 anal., 72% fit
2687.7 ± 1.4 Ma
3 anal., 64% fit
Youngest concordant zircon
2679±4 Ma (T-A1)
2695.2 ± 1.4 Ma
3 anal., 99% fit
youngest zircon
Z2 - 2673.9 ± 1.8 Ma
youngest concordant zircon
Z3 - 2689 ± 11 Ma
^{206}Pb / ^{238}U
^{207}Pb / ^{235}U
(0 Ma)
Z1
Z2
Z3
Z4
Z5
Z6
2620
2640
2650
2660
2670
2680
2690
2700
2710
2720
2740
2750
2800

Figure 33.2. Concordia diagrams with U/Pb analyses of zircon. Ellipses indicate the 2σ uncertainty.

detrital zircon age of 2679±3 Ma providing a maximum depositional age. The detrital zircons from a pebbly sandstone from the Three Nations Formation about 20 km to the east of the above sample location indicate a considerably younger maximum depositional age of 2669±1 Ma (Bleeker 1999).

A sample was taken from a narrow band of Timiskaming assemblage greywacke, directly on top of the Tisdale Group basalts of the Greenstone Nose unconformity at the Dome Mine and should, therefore, be from the basal part of the Dome Formation. The sample (BNB01-T-01) was collected in 267780AC stope (mine co-ordinate 7810E, 8131N, 2517 elevation) approximately 1000 m below surface (*see* Figure 33.1: location 7). Six analyzed grains scatter along the concordia curve between ca. 2710 Ma and 2679 Ma. The youngest concordant grain yields an age of 2679±4 Ma (Figure 33.2D), which represents the maximum depositional age for this sample (Bleeker 2002).

In an early unsuccessful attempt to find hydrothermal monazite for geochronologic analyses, we sampled an auriferous quartz vein and minor wall rock hosted by Timiskaming assemblage conglomerate of the Sedimentary Trough (02JAA-17) at the Dome Mine. The sample was collected in stope 216759AC, approximately 800 m below surface (*see* Figure 33.1: location 8). Quartz, tourmaline, pyrrhotite, pyrite and ankerite are the major mineral components. Hydrothermal monazite and/or rutile were not found in heavy mineral separates. However, light brown, euhedral and subhedral, equant to 2:1 zircons are abundant. Less abundant colourless small prisms represent a distinct grain type. A hydrothermal origin seems unlikely for any of these zircon types. The varied morphologies instead suggest a detrital population derived from the conglomerate, and the age data appear to confirm this. Concordant and near-concordant single-grain ages of 2674±2 Ma, 2685±2 Ma, and 2814±5 Ma were obtained, and 3 small colourless prisms have an average ^{207}Pb/^{206}Pb age of 2695.2±1.4 Ma (99% p.o.f.) (Figure 33.2E). The data indicate that the quartz vein and its conglomerate host are both younger than 2674±2 Ma.

A sample was taken of conglomerate from the Buffalo Ankerite Mine south pit (*see* Figure 33.1: location 9). The clasts were almost exclusively altered mafic metavolcanic rocks. Zircon recovery was very poor, yielding only a few small grains, therefore, only 2 grains were analyzed. These grains yielded discordant results of circa 2682±4 Ma and 2669±7 Ma (Figure 33.2F) suggesting that the conglomerate is part of the Timiskaming assemblage (i.e., younger than ca. 2680 Ma) (Bleeker 2002). Alternatively, if Grenville-age lead loss was dominant, as is common in samples from the Abitibi greenstone belt, the grains may be of circa 2690 to 2700 Ma age and would suggest the sample is from the Porcupine assemblage.

A strongly foliated, tuffaceous to epiclastic unit of intermediate composition was sampled (02JAA-10) in relatively close proximity to the PDF, or one of its splays, northeast of the Nabob Mine in Ogden Township (*see* Figure 33.1: location 10). Bedding and a minor amount of fine-grained quartz grains are evident in the outcrop. In thin section, a strong sericite-defined foliation is crenulated at a high angle to bedding and numerous fine-grained euhedral porphyroblasts of tourmaline are evident. A few colourless to brown, subhedral and anhedral tiny zircons and zircon fragments were recovered from the heavy mineral separate. The varied morphologies suggest a detrital population; this is confirmed by 6 single-grain analyses with ^{207}Pb/^{206}Pb ages ranging from 2673 Ma (1.2% discordant) to 2722 Ma (0% discordant) (Figure 33.2G). Analysis precision is poor in some instances due to a combination of very small grain size and high common Pb. The youngest concordant analysis is 2689±11 Ma and this provides a maximum deposition age. However, based on the youngest age result, deposition most likely occurred after 2673 Ma.

Timing of Gold Mineralization

RHENIUM-OSMIUM AGES OF MOLYBDENITE

Ages have been determined on fine-grained molybdenite, thought to be closely associated with gold mineralization, using Re/Os isotopic techniques at the University of Alberta in an effort to more precisely identify the absolute age(s) for the timing of gold mineralization in Timmins. The results of this work are described below.

A sample of diamond-drill core from the West porphyry intersected in drill hole 528-017 (130.5 to 130.55 m) (*see* Figure 33.1: location 11) has molybdenite as a selvage in a quartz-dominated vein containing visible gold. The results from this sample, 149.98 ppm Re, 94.27 ppm ^{187}Re, 4287.2 ppb ^{187}Os, give a model age of 2670±10 Ma (Creaser 2003). This sample is considered to be the age of the main gold mineralizing event at the Dome Mine.

A sample of diamond-drill core from the Pearl Lake porphyry intersected in drill hole MC03-12 (1085 feet) (*see* Figure 33.1: location 12), which contains molybdenite as well as chalcopyrite in altered porphyry, was analyzed. The results, 325.56 ppm Re, 204.62 ppm ^{187}Re, 9276.3 ppb ^{187}Os, give a model age of 2661±13 Ma (Creaser 2003). This sample is considered to be the age of the copper-gold mineralizing event at the McIntyre Mine.

A sample was collected from a fault structure on the 33 level of the Dome Mine (*see* Figure 33.1: location 13). The fault is in sheared ultramafic metavolcanic rocks of the Tisdale Group. It contains molybdenite and anhydrite. The results from this sample, 105.86 ppm Re, 66.53 ppm ^{187}Re, 3092.5 ppb ^{187}Os, give a model age of 2727±10 Ma (Creaser 2003). This age does not correlate with any known gold mineralization. The model age may imply isotopic inheritance from the Deloro assemblage (2725 to 2730 Ma) by fluid migration along the Dome fault, which is considered to be a splay of the PDF. Outcrops of the Deloro assemblage occur south of the PDF (*see* Figure 33.1).

URANIUM–LEAD AGES ON MONAZITE

Over 30 monazite grains were identified in 12 polished thin sections of ore samples from 195841AC (mine co-ordinate 5600E 4000N 3634 elevation) ore zone at the Dome Mine (*see* Figure 33.1: location 14). From this population, 34 analyses were made from 15 spots in 14 separate grains using SHRIMP II (Salier 2003). All monazite forms in quartz-tourmaline-sericite ± pyrite veins with visible gold disseminated throughout the samples. On a micro-scale, monazite commonly forms as discrete grains in the altered wall-rock fragments in the vein, although, rare monazite crystals also form as inclusions within pyrite. Monazite has a close micro-spatial association with gold, with the two forming adjacent to each other in places. Analyses were made from 15 independent spots on 12 monazite grains yielding 13 usable analyses (concordance from 95 to 105%; Krapez et al. 2000). Thirteen analyses from 6 independent spots in 6 grains yields a weighted mean ^{207}Pb/^{206}Pb age of 2640±5Ma (Figure 33.3).

The majority of data show discordance and a coupled shift toward younger ^{207}Pb/^{206}Pb ages. There are several possible explanations for this result. A younger hydrothermal(?) event either reset the age of gold-related monazite grains or resorbed and replaced sections of older grains, leading to a mixing of multiple generations of monazite within the analyzed volumes. The low-thorium and low-uranium composition of older grains is consistent with a hydrothermal origin, however, the high-thorium composition of younger grains is more akin to metamorphic (or magmatic) examples. Huttonite (thorium silicate, isostructural with monazite) inclusions in monazite grains may have introduced complexities to the data, with a lowering of the apparent age of grains accompanied by discordance of data. The strong correlation recorded between age and geochemistry supports this possibility. Grains with younger ages have a consistently higher thorium content than older more concordant grains. Extreme geochemical compositions of grains, for example, high proportions of light rare earth elements (LREE) substituted for Ce, may lead to an artificial discordance where the rare earth element (REE) concentrations in samples varies significantly from the standards. If this was the case, data that have not been included in age calculations owing to apparent discordance may actually represent valid age information. Therefore, age calculations both inclusive and exclusive of discordant data are given below. It is also possible that two or more of the above listed effects may have affected age data. For example, REE content of grains may be responsible for the apparent discordance, with a shift toward younger ages being related to either inclusions or multiple monazite generations.

By using concordant data only, and disregarding a single analysis with an age of 2623±15 Ma as a statistical outlier, younger grains with high Th–U ratios have an age of 2562±22 Ma (n=2). The age of the entire high Th/U population, disregarding 5 analyses with ages varying from 2600 to 2630 Ma, is 2563±16 Ma (mean square of weighted deviates (MSWD) = 0.01, n = 5).

Although the mechanisms causing varied age and apparent concordance are not well understood in this data set, it is possible to use U and Th contents to divide the data into 2 populations (*see* Figure 33.3a). Under this subdivision, the ^{207}Pb/^{206}Pb age of the older population with low Th/U is 2640±5 Ma (MSWD = 1.3, n = 12). The discordance of the data from this population is potentially an artefact of the composition of the monazites, and appears to have no affect on age, the age of the entire low Th/U population, including discordant data, being 2639±3Ma (MSWD = 1.5, n = 24). However, given that the mechanisms causing discordance in monazite are poorly understood, the more conservative age of 2640±5Ma is probably best used as a minimum age for the sample.

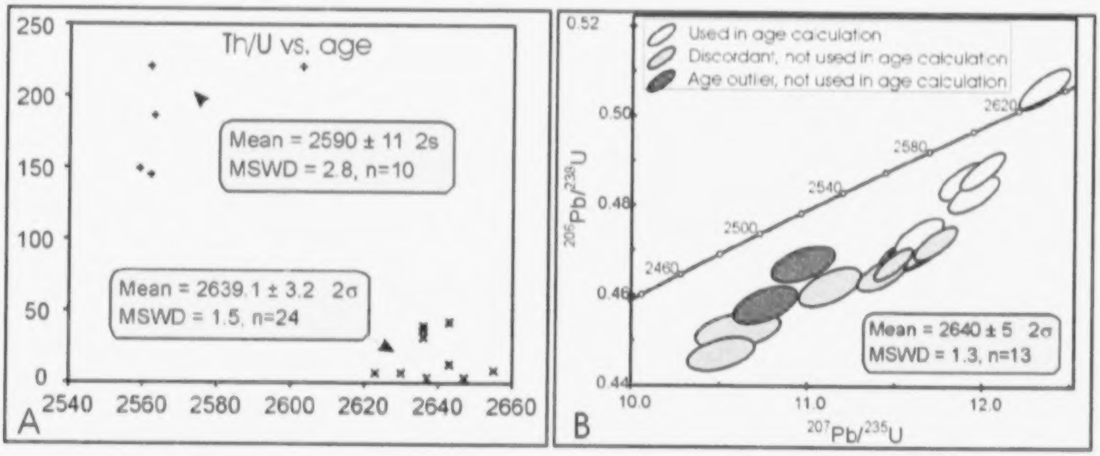


Figure 33.3. a) Plot of all SHRIMP II age data for gold-related monazite from the Dome mine plotted against Th/U. A clear relationship exists between age and geochemistry in the sample set. Only U/Pb data from the first analysis on each spot are shown graphically, with U and Th concentration for second and third analyses assumed to be the same as for the first analysis. b) Concordia diagram for gold-related monazite from the Dome mine. U/Pb data are shown with 1σ error. ^{207}Pb/^{206}Pb age for the low Th/U samples are shown in inset with 2σ error (Salier 2003).

DISCUSSION AND CONCLUSIONS

These new data have important implications for the timing and distribution of late-tectonic stratigraphy and gold mineralization in the Timmins area. On a regional scale, the Krist Formation only occurs at the base of the Porcupine assemblage in the vicinity of Timmins. It is also coeval with calc-alkalic porphyries of similar composition, which are also relatively abundant in the Timmins area. These features suggest that the Timmins area was a centre for calc-alkalic volcanism circa 2687 Ma with the porphyries representing subvolcanic intrusions. The presence of the Krist Formation in southeast Whitney Township, underlying the Whitney Formation turbidites to the east, is at variance with previous stratigraphic interpretations that suggested that the Whitney Formation was intercalated within the Tisdale group (e.g., Pyke 1982; Born 1995). The occurrence of the Krist Formation south of the PDF may represent a marker unit indicating the magnitude of strike-slip displacement on the PDF. This is suggested by the thick accumulation of felsic metavolcanic rocks of the Krist Formation in southeast Whitney Township (probably somewhat enhanced by folding). This new discovery, in conjunction with the absence of the Krist Formation between the Tisdale assemblage metavolcanic rocks and the metasedimentary rocks of the Porcupine assemblage north of the PDF in Whitney Township, implies about 10 to 15 km of sinistral displacement across the fault (*see* Figure 33.1).

The new detrital zircon ages from the Timiskaming assemblage sedimentary units also reveal some interesting insights into tectonic evolution in the Timmins area. The detrital zircon data from epiclastic rocks in the vicinity of the PDF at the Buffalo Ankerite and the Nabob mines (*see* Figure 33.1: locations 9 and 10) provide new evidence for the Timiskaming assemblage occurring west of the Dome Mine. It is likely that these thin Timiskaming assemblage units are preserved slivers of larger units, which were subsequently truncated by movement on the fault.

The maximum depositional age of 2679±4 Ma from the Dome Formation in the Greenstone Nose at the Dome Mine is indistinguishable from the maximum depositional age of 2679±3 Ma (Corfu, Jackson and Sutcliffe 1991) for the Dome Formation sample to the east (*see* Figure 33.1: locations 7 and 6, respectively). The sample from the Sedimentary Trough at Dome has a somewhat younger maximum depositional age of 2674±2 Ma. This is closer to the maximum depositional ages of 2669±1 Ma, from the sample collected from the Three Nations Formation located 15 km east of the map area (Bleeker 1999), and 2674 Ma, from the sliver of the Timiskaming assemblage preserved near the Nabob Mine (*see* Figure 33.1: location 10). It is also similar to the maximum depositional age of 2674±4 Ma from turbiditic sediments that are correlated within the upper part of the Timiskaming assemblage east of Larder Lake (Ayer, Ketchum and Trowell 2002).

Collectively, the new data indicate that the Timiskaming assemblage may have been deposited over a 10 million year period (i.e., 2679 to 2669 Ma). In addition, the oldest zircon from the Sedimentary Trough sample has an age of 2814±5 Ma. This age is very similar to the age of 2816 Ma for the oldest detrital zircon in the pebbly sandstone sample east of the map area (Bleeker 1999), both of which indicate a provenance from a considerably older source than the SAGB and most probably came from the Opatica Subprovince to the north (Ayer, Amelin et al. 2002). This suggests that the lowermost Timiskaming assemblage unit, the Dome Formation, had predominantly local provenance, whereas higher in the Timiskaming assemblage stratigraphy, the Three Nations Formation, had more widespread provenance sources.

Corfu (1993) suggested that the Porcupine assemblage was folded before emplacement of the Timmins porphyries. However, these new data show that the porphyries were emplaced during deposition of the Krist Formation in the basal part of the Porcupine assemblage. Thus, it is likely that the porphyries and the Porcupine assemblage underwent regional deformation after 2687 Ma, but before the unconformable deposition of the Timiskaming assemblage conglomerates at approximately 2680 Ma.

Brisbin and Pressacco (1999) suggested that at least 2 episodes of deformation occurred prior to deposition of the Timiskaming assemblage based on fabric evidence and the truncation of older assemblages and structures by an unconformity at the base of the Timiskaming assemblage. In addition, Gray and Hutchinson (2001) have shown that auriferous boulders occur within Timiskaming assemblage conglomerates, which are themselves crosscut by gold-bearing quartz-carbonate veins at the Dome and Pamour mines. Thus, gold mineralization events may have both preceded and postdated the deposition of the Timiskaming assemblage in the Timmins area.

The presence of gold-bearing veins within the Timiskaming assemblage, and a Re/Os age of 2669±10 Ma for molybdenite associated with gold veins at the Dome Mine, indicates that the main gold mineralization event is constrained to between circa 2670 and 2659 Ma. Geochronological evidence exists for a pre-Timiskaming assemblage (before 2672±2 Ma) disseminated gold event at the Holloway Mine, east of Timmins (Ropchan et al. 2002). However, isotopic evidence for this event is still unclear in the Timmins camp as a less precise Re/Os molybdenite age of 2661±13 Ma for disseminated copper-gold mineralization at the McIntyre Mine is within a similar range as the Dome Mine vein sample. This age does not permit it to be related to the speculated pre-Timiskaming mineralization event, but suggests that the molybdenite at the McIntyre Mine was grown during a subsequent mineralization event.

The U/Pb SHRIMP II ages on the least altered population of monazite provide a minimum age for gold mineralization at the Dome Mine of 2640±5 Ma. These monazites have low Th–U ratios and are interpreted to be of hydrothermal origin, but may have experienced some re-equilibration. A second monazite population has a considerably younger age of 2563±16 Ma. These monazites have higher Th–U ratios and are interpreted to have been re-set. Both monazite population ages are considerably younger than the 2670 to 2660 Ma age range for gold mineralization indicated by the Re/Os data. Powell, Carmichael and Hodgson (1995) indicated a minimum age for regional metamorphism is 2643 Ma in the Rouyn–Noranda area. It is possible that this regional thermal event may be in part responsible for the generally young ages of monazite at the Dome Mine.

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34. Discover Abitibi. Gold Subproject 1. Structures and Gold Mineralization in the Pamour–Hoyle Pond Portion of the Eastern Timmins Gold Camp

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INTRODUCTION

The goals of the Timmins gold project are to identify and characterize the key geological parameters controlling the formation and distribution of gold deposits at the district scale to improve the design of future exploration strategies. Key parameters include outcrop-scale structures, lithological units and alteration facies that control the distribution of the mineralization and/or host the mineralization, for example, the location of, and the role played by, the Timiskaming unconformity, as there is a clear empirical relationship between the location of large gold deposits and proximity to this unconformity (e.g., Dome Mine; Dubé, Williamson and Malo 2003). The spatial and structural relationships between the Porcupine–Destor deformation zone (PDDZ), the Dome fault, and the Hollinger fault will be investigated. Camp-scale research in the Timmins area will be focussed in 2 transect areas. The area from north of the Hoyle Pond–Owl Creek trend to south of the Pamour Mine encompassing the PDDZ to the south was studied in 2003. In 2004, field work will focus on the area from north of the Hollinger–Coniaurium trend to south of the Dome–Buffalo Ankerite occurrences, encompassing the PDDZ to the south.

HOYLE POND–PAMOUR TRANSECT: REGIONAL STRUCTURES

This area (Figure 34.1) is underlain by turbiditic metasedimentary rocks (now considered to be Porcupine assemblage sediments; Berger 1998) overlying basalts and ultramafic rocks (conventionally considered to be lower Tisdale assemblage basalts; Rye 1987). The contact is only accessible in the Porcupine Joint Venture diamond-drill core and, in almost all instances, it is marked by extremely graphitic schist derived from the metasedimentary rocks. This deformed contact is interpreted to represent an early high-strain zone. It has also been described as an unconformity (Pyke 1982), but the basal zone is marked by extremely fine-grained metasedimentary rocks, which are typically intensely deformed. Since diamond-drill core is not oriented for structural purposes, the sense of movement along this high-strain zone has not been determined. There are 2 possibilities being considered: if the two units are indeed correlative with the Porcupine assemblage and the Tisdale assemblage, then the high-strain zone is probably extensional because part of the stratigraphic section has been removed. However, if the high-strain zone is a thrust, then one or the other of the assemblages has been misidentified. To resolve this problem, a sample has been taken from the metasedimentary rocks for geochronology to estimate their maximum depositional age from detrital zircons. To identify the stratigraphic affiliation of the basalts and ultramafic rocks, a suite of samples has been collected and submitted for analysis for major elements and

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an extensive suite of trace elements, including the rare earth elements, and will be compared with results from the well-studied parts of the Tisdale assemblage to the west.

Based on previous and ongoing work (D.A. Rhys, Kinross Gold Corporation, personal communication, 2003), 6 generations of structures are identified in the area (Table 34.1). The high-strain zone described above developed between D_1 and D_2, since it cuts D_1 structures and is folded in D_2. At the present stage of work, the PDDZ has not been assigned a relative age or period of activity.

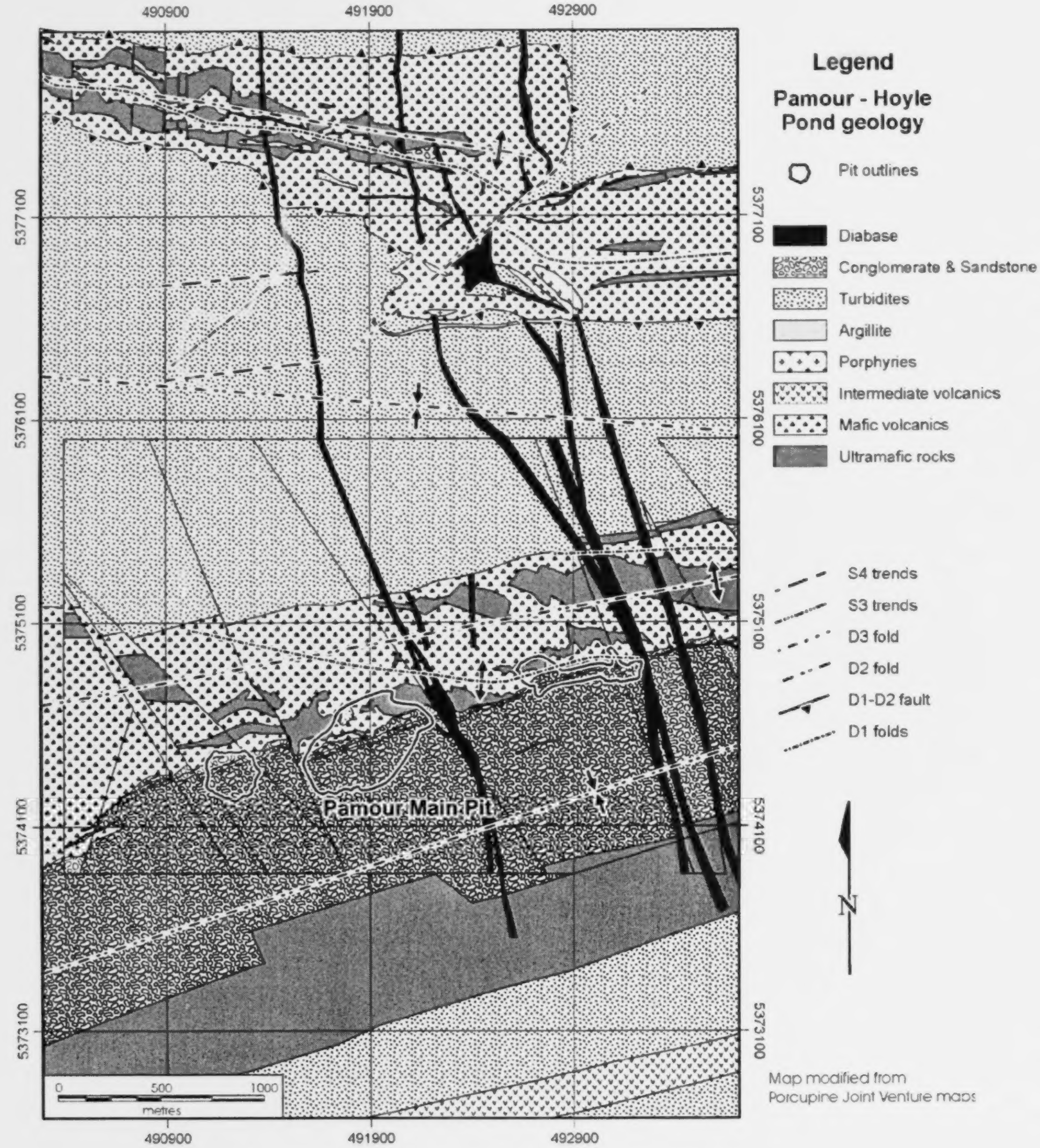
490900
491900
492900
5377100
5376100
5375100
5374100
5373100
Pamour Main Pit
0
500
1000
metres
Legend
Pamour - Hoyle Pond geology
Pit outlines
Diabase
Conglomerate & Sandstone
Turbidites
Argillite
Porphyries
Intermediate volcanics
Mafic volcanics
Ultramafic rocks
S4 trends
S3 trends
D3 fold
D2 fold
D1-D2 fault
D1 folds
N
Map modified from
Porcupine Joint Venture maps

Figure 34.1. Map of the Pamour–Hoyle Pond transect, in the eastern Timmins gold camp.

MINERALIZATION IN THE HOYLE POND–PAMOUR TRANSECT

Gold mineralization is typically situated along the southern edge of the belts of basalt and ultramafic rocks that are exposed as a result of broad-scale D_2 folding. A general model for mineralization is shown in Figure 34.2: along the southern edge of the mafic metavolcanic belts, the D_2 folds have steep overturned limbs. These limbs have an orientation suitable for reactivation of the faulted basalt–sediment contact during D_4 north-northwest shortening and north-block-up faulting, whereas along the northern margin the contact dips more shallowly and is apparently not reactivated in the same manner.

Table 34.1. Six generations of structure in the Pamour–Hoyle Pond transect and their principal characteristics.

EVENT	AXIAL SURFACE ORIENTATION	STRUCTURES DEVELOPED	SIGNIFICANCE
D_6	Shallow-moderate dip northeast strike	Sparse fine crenulations	Regionally very minor
D_5	Steep dip north strike	Sparse kinks and metre-scale folds	Local effects on veins: late stage of quartz veining and gold mineralization
D_4	Moderate-steep dip west-southwest strike	Strong spaced crenulation cleavage, no folds identified	Major event: quartz veining and gold mineralization
D_3	Moderate dip southwest strike	No folds identified constant foliation orientation	Major event: penetrative fabric
D_2	Steep dip west-northwest strike	Broad, overturned to south 2 km half wavelength transected by S_4	Folded fault surface, major map-scale feature
D_1	Moderate dip northwest strike	Tight intermediate-scale folds 500 m half wavelength	Truncated against fault

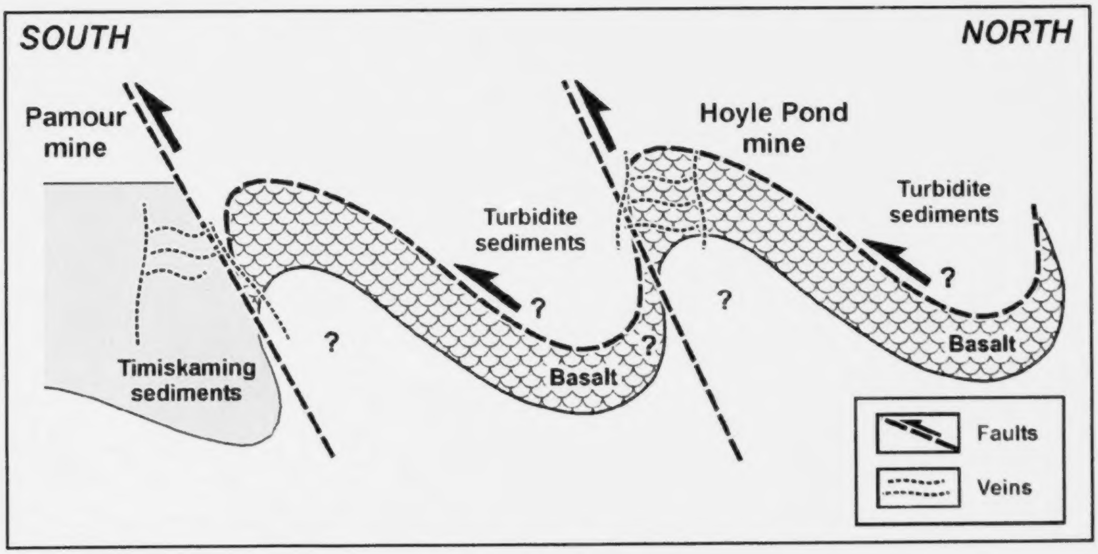

Figure 34.2. Schematic north to south section through folds in the Pamour–Hoyle Pond transect.

PAMOUR GOLD DEPOSIT: HOYLE–PAMOUR–BROULAN PORCUPINE GOLD MINERALIZATION

The Pamour deposit is a Neoarchean quartz-carbonate shear-zone-related gold deposit (also known as "orogenic gold") with a total gold content of 230 metric tonnes (A. Still, Porcupine Joint Venture, personal communication, 2003). The deposit is spatially distributed along the Timiskaming unconformity over a strike length of more than 5 km (Poulsen, Robert and Dubé2000).

Detailed mapping in the Hoyle–Pamour–Broulan Porcupine pits shows that the mineralization is characterized by 2 types of quartz-carbonate veins and associated disseminated sulphide minerals: sheeted fault-fill laminated veins and *en échelon* extension veins. The veins are mainly hosted by folded, but relatively low-strain, Neoarchean Timiskaming assemblage conglomerates and greywackes near the base of the sedimentary sequence, and within subjacent Tisdale assemblage basalt. The extension veins and associated disseminated sulphide minerals in the host Timiskaming assemblage conglomerate contain the bulk of the gold, although the fault-fill veins host the higher grades (Aitken 1990). Laminated fault-fill veins (Photo 34.1) occur in 2 sets within conjugate reverse fault systems: one set dips steeply east-southeast, and a subordinate set dips steeply north-northwest. The fault-fill veins display multiple fracture-opening and vein-fill episodes and contain numerous seams and slivers of wall rock in both sedimentary and mafic metavolcanic host rocks. The host faults are discordant to the stratigraphy and offset bedding. Weakly developed stretching lineations plunge steeply west. The individual extension veins each seem to represent a single vein-fill event. They dip shallowly to moderately to the east-southeast. The extension vein set formed by subvertical extension during conjugate north-northwest–south-southeast shortening represented by the fault-fill veins and the conjugate fault zones that they occupy. On the regional scale, including the Hoyle Pond and Owl Creek mines, mineralization formed on the southern margins of mafic metavolcanic rocks as exposed by D_2 folding.

Veins generally crosscut S_4, although, in some cases, the extension vein tips are gently folded with S_4 axial surfaces and, in the most extreme cases, the veins may be crosscut and modified by pressure-solution processes along S_4 surfaces; hence, the veins formed late in D_4. Another set of small-scale extension quartz-carbonate veins is locally developed in the Broulan pit. They appear to be related to small-scale (10 cm long individual veins dipping shallowly east) second-order extension vein arrays (Photo 34.2). The geometry of these east-dipping arrays of *en échelon* veins is such that east-west, D_5 shortening is implied. Thus, vein timing is constrained to span syn- to late-D_4 (north-northwest–south-southeast shortening) into early D_5 (east-west shortening). This change in the direction of shortening may be explained by an increase in the stress producing east-west shortening during the waning of the orogeny relative to the stress producing north-northwest-directed shortening or changing orientation of the major stress as the orogeny evolved. At that moment, maximum compressive stress became east-west, resulting in the small-scale folds and kinks that characterize D_5. Late D_4 northwest- and north-northeast-trending, dextral and left-lateral faults cut and offset the mineralized zones.

CONCLUSIONS: EXPLORATION SIGNIFICANCE

Of exploration interest is the fact that, in the northern part of the area, in the centre of Hoyle Township, the Porcupine assemblage turbidites show south dips and north facings. This indicates the D_2 folds are overturned to the north, whereas in southern Hoyle Township and in Whitney Township, the folds are overturned to the south. The reason for this is not clear, but its significance is that gold mineralization in the northern part of the area may lie along the northern margins of the basaltic belts. It is possible that many of these conclusions apply to the northern parts of Tisdale Township and the North Tisdale anticline and syncline as well. Thus, the Timiskaming unconformity may be of secondary

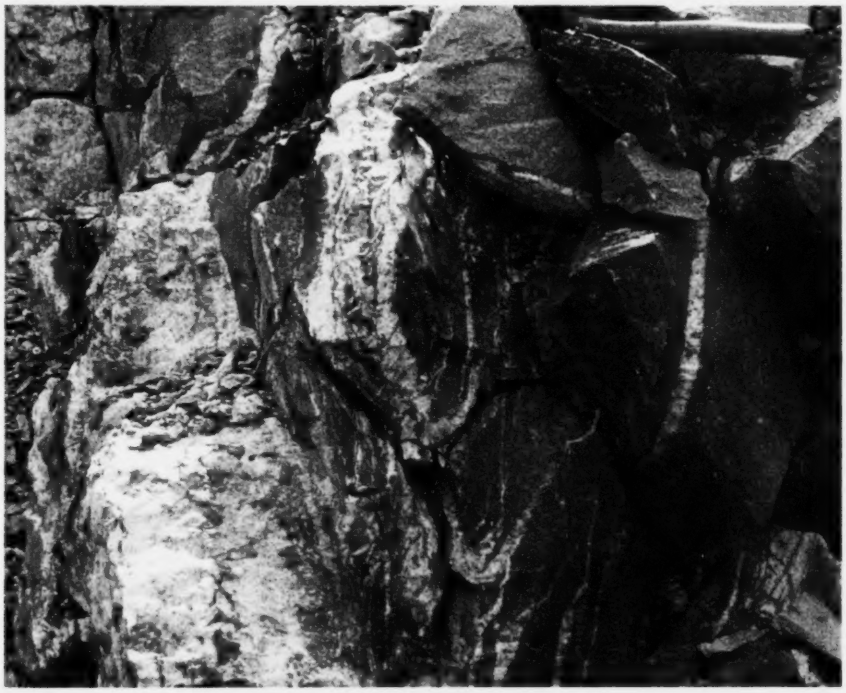

Photo 34.1. In the southern Pamour pit, view to the west of a small laminated fault-fill vein, with associated extension quartz veins indicating south (left) block up.

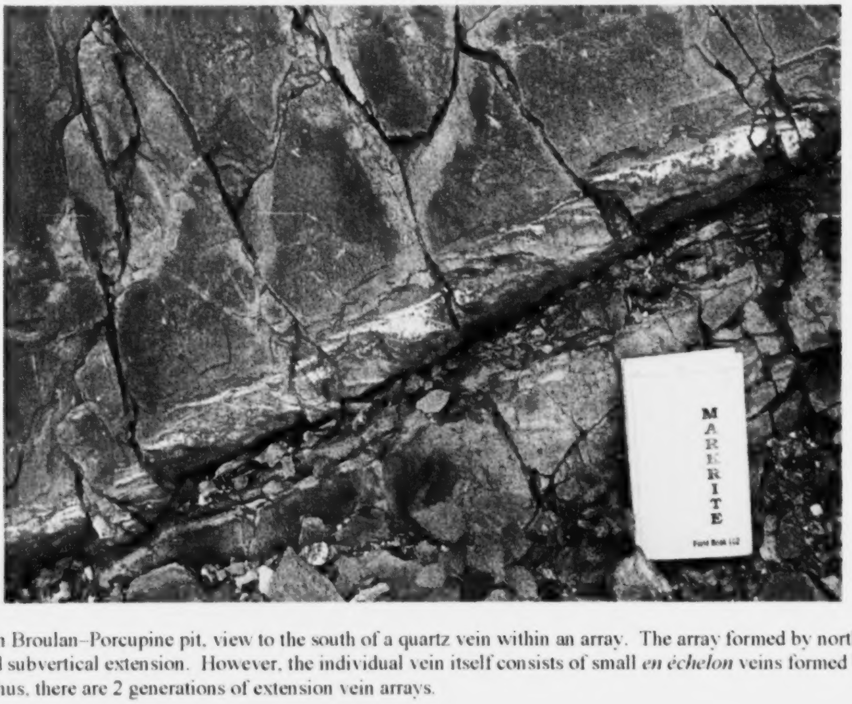

Photo 34.2. In Broulan–Porcupine pit, view to the south of a quartz vein within an array. The array formed by north-south shortening and subvertical extension. However, the individual vein itself consists of small *en échelon* veins formed by east-west shortening. Thus, there are 2 generations of extension vein arrays.

importance in mineralization: quartz vein-gold complexes may have formed essentially along steeply north-dipping zones of D_3 reactivation of the high-strain zone separating the basalts and turbiditic sediments of the Pamour–Hoyle Pond transect. Such reactivation zones may underlie the Timiskaming assemblage metasedimentary rocks and be part of the PDDZ and of the synclinal structure that hosts the Timiskaming assemblage metasedimentary rocks. The competence contrast created by the conglomerates may have served to enhance the propensity for vein formation. Perhaps the important factor is that, without these zones of reactivation, no gold deposits would have formed, the Timiskaming unconformity notwithstanding.

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35. Discover Abitibi. Gold Subproject 2. Geologic Mapping of the Gauthier Township Transect (Kirkland Lake Gold Camp)

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INTRODUCTION

A two-year project funded under the Discovery Abitibi Initiative was started this year with the goal of better understanding regional geologic and structural controls on gold mineralization along the Kirkland Lake "main break" and the Larder–Cadillac deformation zone. The project began this summer with 1:10 000 scale geologic mapping of a 26 km^2 area in Gauthier Township, west of the town of Larder Lake and north of Highway 66. The area encompasses the Larder–Cadillac deformation zone, which hosts the past-producing Anoki and McBean gold mines. The past-producing Upper Canada Mine, which is located 1.7 km northwest of the McBean Mine, occurs along an east-northeast-trending splay of the Larder–Cadillac deformation zone.

Gold exploration began in 1906 (Thomson and Griffis 1944) and continued with varied intensity through the 20th century. The Anoki, McBean, and Upper Canada mines collectively produced 1.57 million ounces of gold (http://www.queenston.ca/; web site accessed October 17, 2003). At present, Queenston Mining Inc. is conducting an exploration diamond-drilling program focussing on targets along the Larder–Cadillac deformation zone (www.queenston.ca).

The area was previously mapped at a scale of 1:12 000 by Thomson and Griffis (1944) and remapped by Jackson (1995) as part of a 1:50 000 scale regional compilation map. The current project is intended to generate an updated detailed geologic map incorporating new observations and structural measurements, critically re-evaluate existing geologic data and results of recent gold exploration programs. At the time of submission of this report, mapping was still in progress, and these results should be considered preliminary.

GENERAL GEOLOGY

The map area (Figure 35.1) comprises Archean mafic and ultramafic metavolcanic rocks of the Larder Lake group (cf. Jackson 1995) of the Tisdale assemblage (Ayer et al. 2002) and alkalic volcano-plutonic rocks and clastic metasedimentary rocks of the Timiskaming assemblage. Metavolcanic rocks of the Gauthier group of the Tisdale assemblage, which occupy the northeast corner of the map area, had not been mapped by the time of submission of this report.

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The Larder Lake group is exposed in the south part of the map area along Highway 66. It consists of variolitic pillowed basalts and ultramafic flows or intrusive rocks with subordinate interflow siliceous exhalites. The metavolcanic rocks are cut by synvolcanic gabbroic intrusions composed of plagioclase and coarse-grained (up to 1–2 cm in length) prismatic amphibole presumably replacing primary pyroxene.

Most of the map area consists of Timiskaming assemblage metavolcanic and metasedimentary rocks. The Timiskaming assemblage includes 2 major types of metasedimentary rocks: polymictic conglomerate interlayered with sandstone, and turbiditic sandstone and siltstone. West of the Upper Canada Mine, undeformed conglomerates are spatially associated with extrusive metavolcanic rocks and subvolcanic intrusions. The conglomerate contains well-rounded subequant to slightly elongate pebbles of feldspar-phyric igneous rocks, quartz porphyries and leucocratic granitoids as well as sandstone, siltstone, tuff, red and black chert and vein quartz. Interbeds of sandstone, varying in thickness from 40 to 50 cm up to

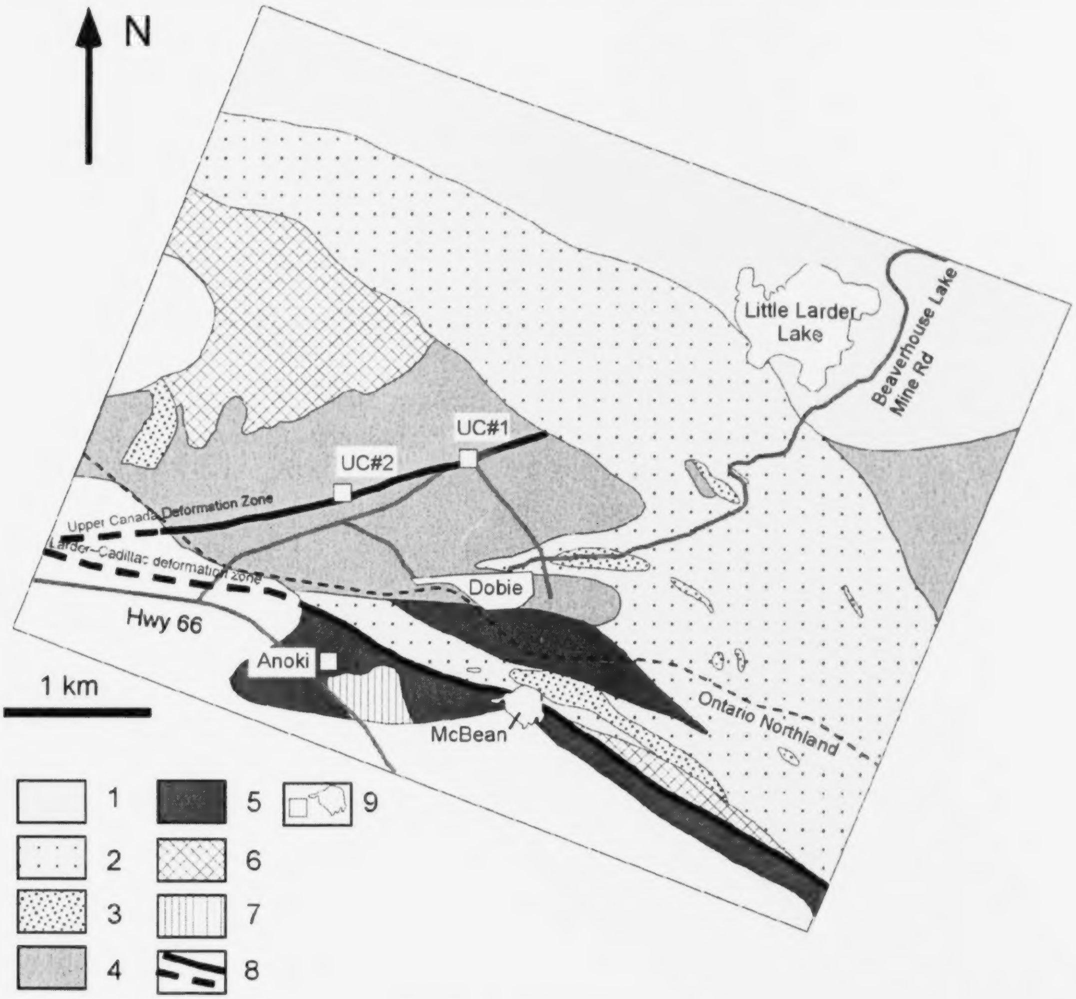
N
Little Larder Lake
Beaverhouse Lake Mine Rd
UC#1
UC#2
Upper Canada Deformation Zone
Larder–Cadillac deformation zone
Dobie
Hwy 66
Anoki
1 km
McBean
Ontario Northland
1
2
3
4
5
6
7
8
9

Figure 35.1. Simplified geologic map of the study area (*modified from* Thomson and Griffis (1944) and Jackson (1995)). Explanations: 1, Gauthier group; 2-4, Timiskaming group (2, turbidites; 3, conglomerates; 4, volcanic rocks); 5, Larder Lake group; 6, syenite-porphyry and quartz-feldspar porphyry intrusions; 7, gabbro intrusion; 8, major shear zones; 9, mines (UC#1 and UC#2, Upper Canada Mine shafts #1 and #2, respectively).

several metres, are interlayered with beds of conglomerate. Near the southern margin of the Larder–Cadillac deformation zone, where deformation is particularly strong and carbonate alteration is intense, volcanic clasts are completely carbonatized and stretched into ribbons and bands. Only clasts of leucocratic granitoids, chert and quartz, which are both resistant to alteration and rheologically competent, survived the intense alteration and deformation. Elsewhere in the map area, conglomerates are weakly to strongly deformed and invariably associated with turbiditic sandstone and siltstone. Turbiditic metasedimentary rocks consist of grey to light greenish grey sandstone and siltstone beds interlayered with thinly laminated greyish-green to dark green argillite beds. Sandstones are rich in detrital feldspar with less quartz. Normal graded bedding consistently indicates tops to the south.

Metavolcanic rocks of the Timiskaming assemblage, north of the Upper Canada Mine, are undeformed to weakly deformed. They consist of aphyric and porphyritic trachytic flow rocks with euhedral prismatic feldspar phenocrysts, more mafic amphibole-phyric flows and volcanic breccias. The breccias typically consist of angular to subrounded fragments (1–2 cm to 20–30 cm) of brown and reddish-brown feldspar-phyric rocks enclosed within a dark green chloritized matrix. Small prismatic to acicular feldspar microlites in the clasts and matrix, as well as locally observed transitions from breccias to massive and flow-banded brown feldspar-phyric lavas, suggest that the breccias are extrusive flows rather than pyroclastic flows. Bedded tuffs and interflow sedimentary rocks are locally associated with the extrusive volcanic rocks.

Timiskaming assemblage metavolcanic and metasedimentary rocks are intruded by late quartz-feldspar porphyry, syenite porphyry and biotite lamprophyre of probable Timiskaming age, and by Paleoproterozoic Matachewan diabase dikes.

STRUCTURE AND DEFORMATION FABRICS

The most significant structural feature in the area is the southeast-striking Larder–Cadillac deformation zone. This is a 400 m wide high-strain zone that separates mafic metavolcanic rocks and gabbroic intrusions of the Larder Lake group from volcanic and clastic rocks of the Timiskaming assemblage (*see* Figure 35.1). The southern 50 to 150 m of the structure is a zone of extensive shearing and carbonate-chlorite-fuchsite alteration informally named the "green carbonate zone". The northeast-striking Upper Canada deformation zone is the second largest deformation zone in the area and it likely represents a splay of the Larder–Cadillac deformation zone. The rocks between the Larder–Cadillac and the Upper Canada deformation zones are pervasively foliated. To the north of the Upper Canada deformation zone, a pervasive foliation is observed for roughly 400 m. Four generations of penetrative deformation fabrics have been identified during this study, in agreement with the detailed structural study by Toogood (1989) on the "L" mineralized zone at the Upper Canada Mine.

An early regional fabric is reported in the Kinojevis assemblage, Blake River assemblage and Gauthier group of the Tisdale assemblage, which are unconformably overlain by Timiskaming assemblage rocks to the south. As all fabrics in the map area overprint the Timiskaming assemblage rocks, the earliest fabric in the Timiskaming assemblage is a second-generation structure (Wilkinson, Cruden and Krogh 1999). S_2 is a steeply dipping penetrative foliation that is generally parallel to original lithologic contacts. S_2 is the main foliation in the Larder–Cadillac and Upper Canada deformation zones. For most of the area, the orientation of this fabric varies from east-southeast (100 to 110°) along the Larder–Cadillac deformation zone to east-northeast (070°) along the Upper Canada deformation zone. A stretching lineation (L_2) defined by elongate pebbles in Timiskaming assemblage conglomerate and by elongate varioles in Larder Lake pillow basalt is associated with S_2. L_2 typically plunges 40 to 60° to the east. At the Upper Canada Mine, S_2 is defined by hydrothermal chlorite, carbonate and sericite, and it controls the orientation of the mineralized zone (Toogood 1989), as well as concordant quartz–carbonate veins throughout the area.

An S_3 foliation overprints S_2 along the Upper Canada deformation zone. It is also observed on one outcrop in the northern margin of the Larder–Cadillac deformation zone. S_3 is a steeply dipping, north-trending, differentiated crenulation cleavage defined by discrete, dark, sericitic and chloritic cleavage domains (1 to 2 mm wide) separating wider feldspar and quartz domains (3 to 10 mm) in which S_2 is finely crenulated. S_3 is axial planar to open, asymmetrical S-shaped folds that overprint S_2 and concordant quartz veinlets.

S_4 is a steeply dipping, northeast-trending regional cleavage. It is axial planar to Z-shaped folds. S_4 changes orientation from northeast-trending to east-trending near the Larder–Cadillac deformation zone. A similar change in S_4 orientation is observed along the Upper Canada deformation zone at the "L" mineralized zone near Shaft 2 of the Upper Canada Mine. S_4 is east-northeast-trending, but it becomes east-trending in narrow zones of intense deformation, where S_3 and S_2, the main foliations along the deformation zone, are transposed parallel to S_4. Toogood (1989) suggested that this overprinting deformation event (S_4) was accompanied by hydrothermal redistribution of gold based on gold-grade distribution and alteration patterns. We observed concentrations of fine pyrite along S_4 planes, which supports the possibility of sulphide and gold redistribution.

S_5 is a late crenulation cleavage, trending 130 to 170° and dipping 30 to 80° west. S_5 overprints all other fabrics, however, this deformation event is not associated with any map-scale structures.

Slip Movement Direction Along the Larder–Cadillac Deformation Zone

Asymmetric shear sense indicators were observed at 2 localities along the Larder–Cadillac deformation zone:

1. near the northern margin of the Larder–Cadillac deformation zone (Queenston Mining Inc. stripped outcrops at the Princeton Property, east part of the map area)
2. along the contact between Timiskaming assemblage conglomerate and gabbroic intrusions of the Larder Lake group (north wall of the flooded McBean Mine open pit)

Shear sense indicators include asymmetrical strain shadows around pebbles in deformed Timiskaming assemblage conglomerate; dextral Z-shaped drag folds; clockwise orientation of extensional quartz-carbonate veins with respect to foliation; and offsets of these quartz-carbonate veins. The slip movement direction is dextral south-side-up along the plunge (40 to 60°) of the stretching L_2 lineation.

GOLD MINERALIZATION

The Anoki, McBean and Upper Canada gold mines produced 3500, 45 900 and 1 520 503 ounces of gold, respectively (Queenston Mining Inc. web site: www.queenston.ca). At present, mineralization can only be observed at surface at the Upper Canada Mine, where the most productive "L" zone is uncovered by power stripping west of Shaft 2. The mineralized zone is mainly hosted in strongly sheared metavolcanic rocks of the Timiskaming assemblage. The host rocks contain feldspar porphyroclasts, suggesting that they are volcanic in origin. Breccias consisting of flattened angular volcanic fragments (1 to 10 cm in length), and sedimentary rocks (possibly tuffaceous) are observed on the outcrop, but they are less abundant than the feldspar porphyroclastic rocks. Quartz-feldspar porphyry intrusions intrude the metavolcanic rocks. Gold mineralization is localized in a zone of strong carbonatization and sericitization with quartz veins, stringers and silicified ore zones (Toogood 1989). Within the mineralized zone, gold is reportedly associated with quartz veinlets and is commonly hosted in fractured pyrite (Tully 1963). Minerals that were identified in the ore zones are pyrite, telluride minerals, sphalerite, tennantite, chalcopyrite, galena, arsenopyrite and molybdenite (Tully 1963). The "L" zone plunges 48° east (Tully 1963). Mineralization is thought to have formed during the development of S_2, and it has undergone additional structural and hydrothermal modification in S_4 transposition zones (Toogood 1989).

Gold mineralization at the Anoki Mine is not exposed at surface. Based on available information (Thomson and Griffis 1944; www.queenston.ca), the mineralized zone is hosted in basalts of the Larder Lake group i[illegible]e hanging wall of the Larder–Cadillac deformation zone. The ore occurs in a diffuse zone of alteration [illegible] silicification that is subparallel to lithologic contacts and may be controlled by a discontinui[illegible]n the lava sequence or a rheologically favourable horizon, possibly a concordant intrusion. The orebody dips 60° northeast and rakes to the southeast at about 35°. The zone consists of quartz veins and veinlets that are orthogonal to the elongation of the body. Gold values are associated with patches of pyrite (Thomson and Griffis 1944). This mineralization likely represents a stacked array of extensional quartz veins possibly accompanied by a metasomatic replacement of geochemically favourable host rocks.

The gold mineralization at the McBean Mine is confined to zones of sulphidization (pyrite) and quartz veining and is largely hosted in fuchsitic-carbonate altered rocks along the south margin of the Larder–Cadillac deformation zone (i.e., "green carbonate"). Mineralized zones dip steeply south-southwest and rake at approximately 40 to 50° to the east, which is consistent with mineralized zones at the Upper Canada and Anoki mines (Queeston Mining Inc.: *see* www.queenston.ca for report, cross- and longitudinal-sections).

In spite of differences in styles and host rock assemblages, mineralized zones at the 3 mines share important structural similarities. Mineralization is spatially associated with extensive shear zones (Larder–Cadillac and Upper Canada deformation zones), and the ore zones plunge 40 to 60° and are parallel to the stretching L_2 lineation along S_2. This suggests that mineralization was deposited either during or before the development of the deformation zones. Further structural, lithogeochemical and compilation work will be done to better constrain the primary controls on gold mineralization, as well as the effects of later deformational phases.

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36. Discover Abitibi. Gold Subproject 3. Preliminary Regional Geological Assessment of Porphyry Intrusions Spatially Associated with Gold Deposits in the Western Abitibi Subprovince, Timmins, Ontario

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INTRODUCTION

As part of the two-year Discover Abitibi Initiative, this article presents preliminary observations of porphyry intrusions spatially associated with gold deposits in the Timmins camp. Numerous quartz-feldspar porphyry bodies were examined over the summer of 2003 and this article will report and discuss field observations collected to date.

Although most of the porphyry bodies have been the focus of numerous past studies (Gorman, Kerrich and Fyfe 1981; Mason and Melnik 1986; Wood et al. 1986; Burrows and Spooner 1986; Brisbin 1997; Gray and Hutchinson 2001), much debate exists on various aspects of understanding. It is the aim of this project to

- create a regional lithogeochemical data set of the various porphyry intrusions and alteration patterns
- compare and contrast field relations and association of gold mineralization with porphyry intrusions within different areas of the camp
- re-evaluate porphyry bodies for possible evidence of extrusive origin or a correlation with the Krist Formation
- examine chemical trends of mineralized and barren porphyry intrusions
- evaluate the debate of syngenetic copper porphyry ± gold mineralization (Mason and Melnik 1986) versus epigenetic lode gold mineralization (Burrows and Spooner 1986)

REGIONAL GEOLOGY

Most gold deposits within the Timmins camp are hosted within volcanic flows of the Tisdale assemblage (2710 to 2703 Ma) (Ayer, Ketchum and Trowell 2002). These flows range in composition from ultramafic at the bottom of the assemblage (Hersey Lake Formation) through tholeiitic (Central and Vipond formations) in the upper units of the Tisdale assemblage (Pyke 1982; Brisbin 1997). The calc-alkalic felsic metavolcanic rocks of the overlying Krist Formation (2687 Ma) were originally identified as part of the upper Tisdale assemblage (2710 to 2707 Ma), but new geochronological results show they occur at the base of the overlying Porcupine assemblage (Ayer, Ketchum and Trowell 2002).

Summary of Field Work and Other Activities 2003,
Ontario Geological Survey, Open File Report 6120, p.36-1 to 36-7.

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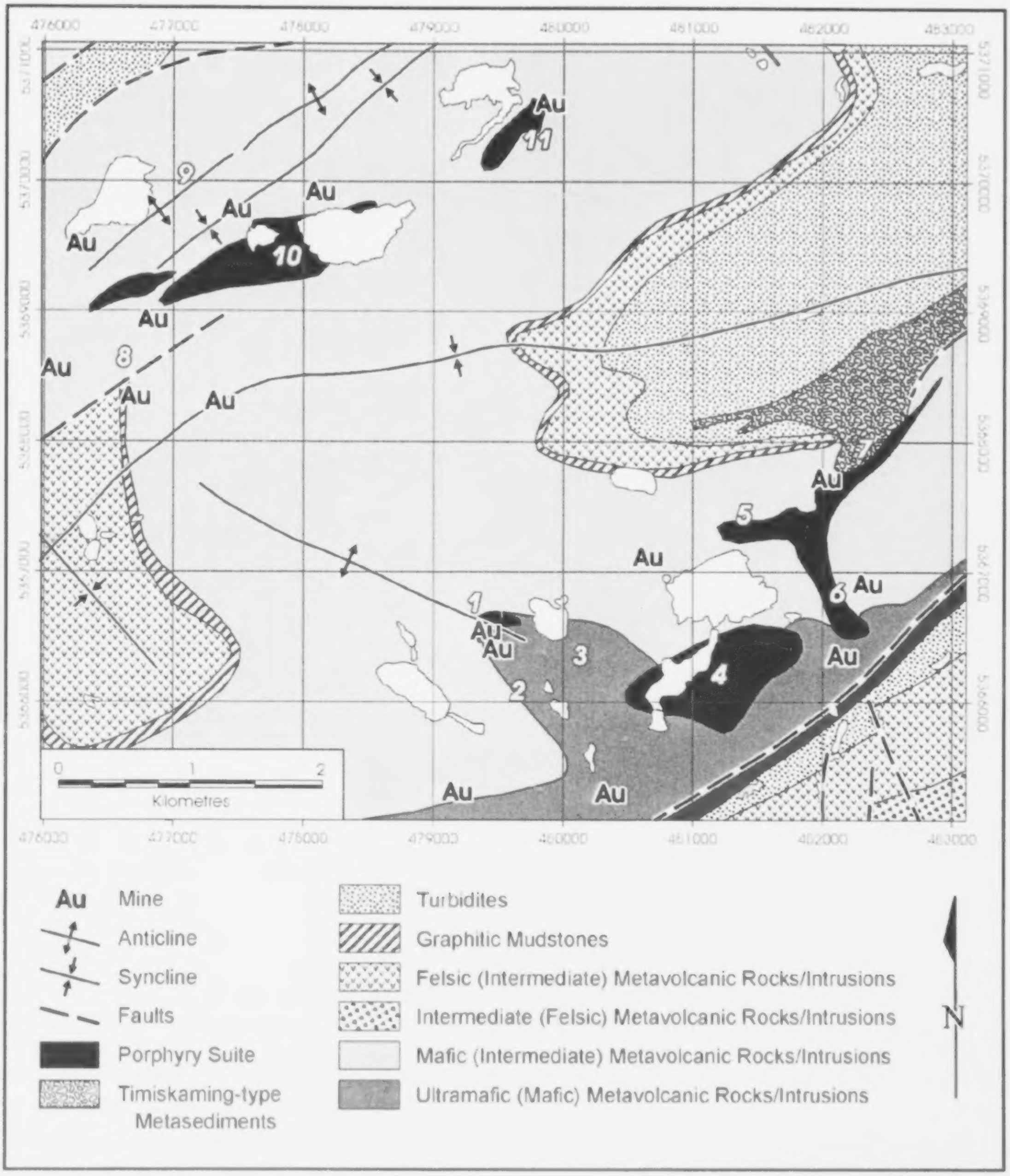
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Porphyry Suite
Timiskaming-type Metasediments
Turbidites
Graphitic Mudstones
Felsic (Intermediate) Metavolcanic Rocks/Intrusions
Intermediate (Felsic) Metavolcanic Rocks/Intrusions
Mafic (Intermediate) Metavolcanic Rocks/Intrusions
Ultramafic (Mafic) Metavolcanic Rocks/Intrusions
N

Figure 36.1. Generalized geological map showing distribution of porphyry bodies examined in the Vedron–Paymaster–Dome and Hollinger–McIntyre–Coniaurium trends (*modified from* Ayer, Berger and Trowell, 1999). Numbers correspond to porphyry bodies: 1) Edwards, 2) Buffalo Ankerite #5, 3) Northwest, 4) West, 5) Paymaster, 6) Preston, 7) Dome Fault Zone, 8) Crown, 9) Gillies Lake, 10) Pearl Lake and 11) Coniaurium.

Numerous porphyry intrusions (ca. 2689 Ma) lie conformably with, as well as crosscut, stratigraphy and intrude 2 main horizons of the Tisdale assemblage (Corfu et al. 1989). The lower horizon is near the Hersey Lake Formation–Central Formation contact and the upper horizon is within the Vipond Formation. Both horizons of quartz-feldspar porphyry intrusions display a close spatial association with gold mineralization.

QUARTZ-FELDSPAR PORPHYRY BODIES

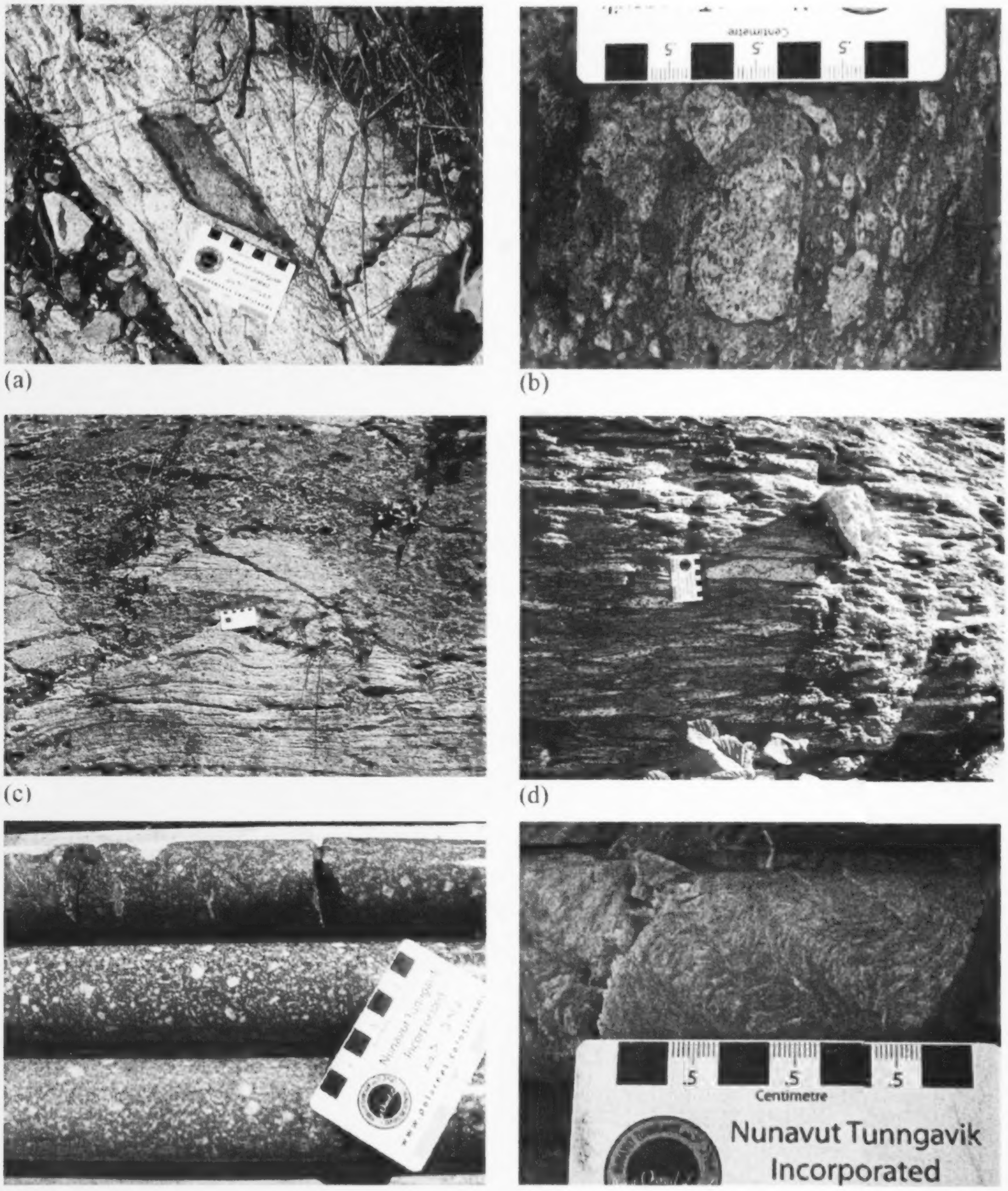
Thirteen different quartz-feldspar porphyry bodies were examined in 2003 with most of their locations shown in Figure 36.1. These porphyry bodies have been geographically grouped into the Vedron–Paymaster–Dome trend, Hollinger–McIntyre–Coniaurium trend and the eastern porphyry bodies. Observations of each trend are described below.

Vedron–Paymaster–Dome Trend

The Vedron–Paymaster–Dome trend of quartz-feldspar porphyries encompasses (from west to east): the Edwards (Vedron), Buffalo Ankerite #5, Northwest (Paymaster #2-3, South Paymaster), West (West Preston), Paymaster, Preston and Dome Fault Zone porphyries. These porphyry bodies align in a southwest trend and individual intrusions plunge to the east (E. Barr, Porcupine Joint Venture, personal communication, 2003). All of these porphyries intrude at or near the Hersey Lake Formation–Central Formation contact and conform with, as well as, crosscut stratigraphy. Phenocrysts of quartz and feldspar (mostly plagioclase) range from 1 to 3 mm in diameter surrounded by a feldspar-rich, very fine-grained matrix, which is commonly altered to white mica; pyrite is in minor abundance in most of the porphyry bodies. Most porphyry bodies contain green mica clasts up to 10 cm long (Photo 36.1a), which are most abundant near contacts, and are typically elongated with the foliation. These porphyry bodies are generally massive, medium grained and have sharp contacts with the surrounding wall rocks. Two exceptions are 1) the northern contact of the Vedron porphyry where subrounded porphyry fragments are present in a fine-grained chloritic matrix of mafic metavolcanic rocks (Photo 36.1b); and 2) the western nose of the Paymaster porphyry where one large flow-banded porphyry fragment is within a fine-grained chloritic matrix of mafic metavolcanic rocks (Photo 36.1c).

All of the porphyry bodies show white mica alteration with localized ankerite, chlorite and biotite alteration. Sericite alteration is most intense in the Dome area (Paymaster, Preston and Dome Fault Zone porphyries) and ankerite alteration is the most intense in the central porphyry bodies (Northwest and West porphyries).

All of the porphyry bodies show at least one recognizable phase of deformation, which includes a spaced cleavage developed axial planar to the South Tisdale anticline at the Vedron property. Locally, an older, more penetrative foliation is observed subparallel to the spaced cleavage. Multiple generations of quartz (± tourmaline) veins are present in local abundances in most of the porphyry bodies. Ankerite alteration increases in pyrite content and tourmaline stringer veins are often associated with the zones of quartz veining.



(a) (b) (c) (d) (e) (f)

Photo 36.1. Photographs of observed features described in the text. a) Large green mica clasts, Edwards porphyry. b) Porphyry clasts in fine-grained, chloritic mafic metavolcanic matrix, Edwards porphyry. c) Large fragment of flow-banded Paymaster porphyry in fine-grained mafic volcanic matrix, Paymaster porphyry nose. d) Stretched porphyry clasts in a fine-grained, chloritic mafic metavolcanic matrix, Shania Twain Centre breccia, Crown porphyry. e) Fresh, unaltered quartz-feldspar phenocrysts, Gillies Lake porphyry. f) Crenulated foliation defined by white mica, Pearl Lake porphyry.

Hollinger–McIntyre–Coniaurium Trend

The Hollinger–McIntyre–Coniaurium trend includes 8 separate porphyry bodies, but only 4 (Crown, Pearl Lake, Gillies Lake and Coniaurium) were examined in 2003. These porphyries have intruded the Vipond Formation and lie in a southwest trend that plunges east-southeast. These porphyry bodies typically have 1 to 3 mm quartz phenocrysts, but, as a result of white mica alteration, feldspar (plagioclase) phenocrysts vary from fresh to completely obliterated. Pyrite is present in trace amounts in all the porphyry bodies, but is more abundant and is present with chalcopyrite in the Pearl Lake porphyry. Green mica clasts are rare but present in the porphyry bodies. Most observed contacts were sharp, tectonic boundaries, except at the Crown porphyry where stretched clasts of porphyry are hosted in a fine-grained chloritic metavolcanic matrix (Photo 36.1d).

The Crown porphyry shows moderate sericite alteration; whereas the Gillies Lake porphyry has a fresh appearance (Photo 36.1e) and shows only weak sericite alteration. The Pearl Lake and Coniaurium porphyries show strong sericite and/or muscovite alteration with feldspars nearly completely replaced. The rock is best described as quartz-sericite schist. The Pearl Lake porphyry, which was observed in diamond-drill core only, also shows zones of hematite, ankerite and chlorite alteration, but the extent of these zones is not yet known.

At least 3 generations of fabrics are present in the Pearl Lake porphyry including a steep penetrative foliation, a subparallel steep-spaced cleavage and a shallow crenulation cleavage (Photo 36.1f). In contrast, the Gillies Lake porphyry shows only minor deformation (weak foliation). Multiple generations of quartz (± tourmaline ± ankerite) veining were observed in the Crown and Pearl Lake porphyries with minor pyrite and chalcopyrite as well as trace visible gold. The veins typically have bleached porphyry selvages that contain above background gold values (P. Harvey, Porcupine Joint Venture, personal communication, 2003).

Eastern Porphyry Bodies

Two eastern porphyry bodies (Pamour and Carr Township) were examined in 2003. The Pamour porphyry occurs in Whitney Township southwest of the Pamour Mine. It is hosted by ultramafic flows that have been altered to talc-chlorite schist. The Pamour porphyry is relatively fresh and is a quartz-feldspar biotite-bearing porphyry with minor pyrite. Phenocrysts average 1 to 2 mm in diameter. Biotite clots up to 2 cm in diameter are randomly distributed throughout the porphyry, with some clots showing green mica alteration to biotite. Very little alteration and deformation is present with only a weak foliation developed locally.

The Carr Township porphyry is a large body that was mapped as being hosted in Porcupine assemblage metasedimentary rocks (Ayer, Berger and Trowell 1999); however, mafic metavolcanic lithologies were observed in diamond-drill core at the contact with the porphyry. The porphyry is a relatively undeformed quartz-feldspar porphyry with phenocrysts up to 4 mm in diameter. Alteration is intense with hematite, potassic feldspar, sericite, chlorite and ankerite alteration present in sporadic zones. Significant pyrite is hosted within the porphyry, but only where minor quartz veining is present. Both sharp and irregular fragmental units of porphyry clasts in a fine-grained, chloritic mafic metavolcanic matrix define the porphyry contacts.

SUMMARY AND DISCUSSION

Although all of the porphyry bodies on the Vedron–Paymaster–Dome trend show similar primary mineralogy (quartz-feldspar), alteration mineralogy (sericite, ankerite and chlorite) and deformation (at least one generation), there are some key differences between those which are spatially associated with small gold deposits and those which are peripheral to the larger gold deposits. The porphyry bodies spatially associated with the small occurrences (Vedron, Buffalo Ankerite #5, Paymaster #2-3, and the West porphyries) show only weak to moderate sericite alteration, moderate ankerite and minor sulphide minerals (spatially associated with the most intense ankerite alteration), whereas Paymaster, Preston and Dome Fault Zone porphyries in the vicinity of the larger gold occurrence (i.e., the Dome Mine) show more intense sericite alteration and minor sulphide minerals without any associated ankerite alteration. Furthermore, the large gold occurrence (Dome) is situated where 3 porphyry bodies are in close proximity (a few metres apart), whereas, in the smaller occurrences, the porphyry bodies are not closely clustered together.

The porphyry bodies in the Hollinger–McIntyre–Coniaurium trend do not show the same relationship to gold mineralization as those in the Vedron–Paymaster–Dome trend. The Hollinger–McIntyre–Coniaurium trend porphyries are situated in a much larger sericite-chlorite-ankerite alteration zone that is pervasive, occurring in both the porphyries and the peripheral mafic metavolcanic rocks. Therefore, the relationship of alteration and gold is only represented by comparing the Gillies Lake porphyry with the other porphyry bodies. The Gillies Lake porphyry is outside of the alteration zone and appears relatively fresh, whereas the porphyries in the main gold zone contain sericite, ankerite, chlorite and hematite alteration. As well, the porphyries in the gold-related alteration zone exhibit intense deformation including the development of multiple fabrics, shear zones, and brittle faults, features that are not observed in the Gillies Lake porphyry.

The eastern porphyry bodies are different from the other two trends in both appearance and association with mineralization, and the alteration is different in both porphyries examined (Pamour and Carr Township). The Pamour porphyry shows only biotite alteration whereas the Carr Township porphyry exhibits sericite, hematite, potassic, ankerite and chlorite alteration. Deformation is weak in both porphyries with only a weak fabric. It is still unclear what the exact spatial relationship of the Pamour porphyry is to gold mineralization. Minor gold mineralization is associated with the altered Carr Township porphyry; however, the apparent lack of deformation might explain the relatively low abundance of gold associated with this porphyry.

Preliminary observations from this research suggests that gold mineralization is most strongly correlated with the porphyry bodies in the Timmins camp that are associated with intense sericite alteration coupled with moderate ankerite alteration in intensely deformed areas of the belt.

ACKNOWLEDGMENTS

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37. Discover Abitibi. Metamorphic Subproject. Metamorphism and its Relationships to Gold Deposits in the Timmins–Kirkland Lake Area, Western Abitibi Greenstone Belt, Ontario: Report 1

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INTRODUCTION

During the metamorphism of volcano-sedimentary rock units and related intrusions that occurred during formation of the gold-rich Abitibi greenstone belt, mineralogical and textural changes produced metamorphic features with excellent, but as yet, under-utilized, potential as gold exploration tools. Boundaries between belt-scale metamorphic zones, smaller scale "hot" and "cold" spots, and steep metamorphic gradients (closely spaced isograds) outline areas where anomalously high heat and/or fluid flow may have occurred. Therefore, metamorphic data and concepts impose a variety of constraints on the mobilization, transport, and deposition of gold and on the age, timing, and nature of related alteration. Metamorphic zone boundaries are recognized as favourable prospecting features in the Kalgoorlie region of Western Australia (Hall 1998; Mikucki and Roberts 2003). In the Timmins area (Figure 37.1), a pilot study supported by Placer Dome and the Ontario Geological Survey (OGS) revealed that a number of gold mines and occurrences coincide with newly defined metamorphic anomalies (Thompson 2002). Recently completed metamorphic studies in the Yellowknife (P.H. Thompson, unpublished data, 2003) and Red Lake (Thompson, in press) greenstone belts have identified previously unrecognized metamorphic features that may represent new gold exploration targets. The Discover Abitibi Metamorphic Subproject is designed to fill a significant knowledge gap in the Timmins–Kirkland Lake area and to define new metamorphic targets for gold exploration. This report integrates new metamorphic data obtained from OGS thin sections from the Watabeag Lake area (Sheraton, Timmins, McEvay, Michie and Nordica townships) with the geological setting described by Vaillancourt (2001). This is an example of the work to be done on a much larger scale during the two-year mandate of the Discover Abitibi Greenstone Architecture Project.

METHODOLOGY

Covering approximately 11 000 km^2, including the 9 townships incorporated into the Timmins pilot study (Thompson 2002), this project will involve the regional petrography of hundreds of thin sections archived by the Ontario Geological Survey and of new samples collected during the field component of the current study. Compilation, analysis, and interpretation of the new data from the Timmins–Kirkland Lake area will enhance and extend the metamorphic framework first outlined at a regional scale by Jolly

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Summary of Field Work and Other Activities 2003, Ontario Geological Survey, Open File Report 6120, p.37-1 to 37-8.

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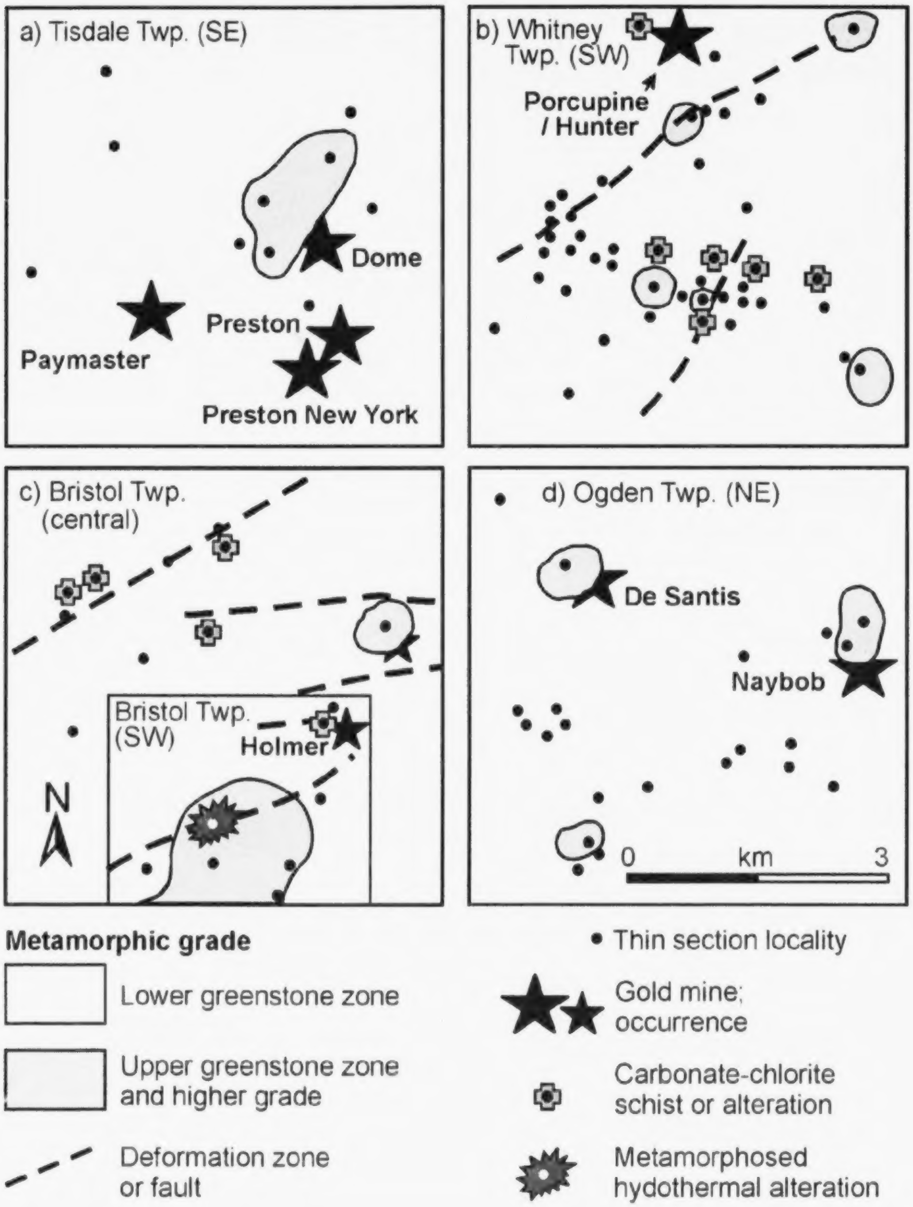
a) Tisdale Twp. (SE)
Dome
Preston
Paymaster
Preston New York
b) Whitney Twp. (SW)
Porcupine / Hunter
c) Bristol Twp. (central)
Bristol Twp. (SW)
Holmer
N
d) Ogden Twp. (NE)
De Santis
Naybob
0
km
3
Metamorphic grade
Lower greenstone zone
Upper greenstone zone and higher grade
Deformation zone or fault
Thin section locality
Gold mine; occurrence
Carbonate-chlorite schist or alteration
Metamorphosed hydothermal alteration

Figure 37.1. Defined by mineral assemblages in metamorphosed basalts and/or gabbro (metabasite), the greenstone zone corresponds approximately with the greenschist facies of regional metamorphism. The zone is divided into upper and lower greenstone zones by a line marking the appearance of biotite in metamorphosed quartzofeldspathic and aluminum-rich rocks, and amphibole in meta-ultramafic rocks that are associated with metabasites. On schematic maps of parts of 4 townships in the Timmins area—a) Tisdale, b) Whitney, c) Bristol and d) Ogden—there is an apparent correlation between the relatively high-grade metamorphic anomalies and gold mines. Note that control on the size and shape of these metamorphic anomalies, taken *from* Thompson (2002), varies from poor to quite good.

(1978) and refined by several detailed local studies (e.g., Powell et al. 1993). Mineral assemblages and textures observed in thin section will be the basis for

- determination of 8 rock associations (generalized rock types)
- estimates of the pressures and temperatures associated with major metamorphic events
- constraints on the timing, duration and depths of deformation and plutonism
- temporal and spatial constraints on the type, intensity, and timing of alteration and gold mineralization

Highlights of the results obtained from part of the first batch of 648 thin sections are presented in this preliminary report.

RESULTS

This study advances knowledge of the geological setting of known gold mineralization and points to several new areas that may be favourable for gold exploration. Of the 103 thin sections investigated, 20 were redundant and 3 lacked diagnostic metamorphic assemblages. The remaining 80 samples are distributed as follows:

1. 29 metabasites (metabasalt and/or gabbro)
2. 34 metamorphosed quartzofeldspathic rocks (metasandstones, metamorphosed felsic flows and volcaniclastic rocks, quartz-feldspar metaporphyries)
3. 1 meta-ultramafic rock
4. 2 aluminum-rich schists
5. 3 meta-iron formations
6. 4 metagranitoids
7. 4 metamorphosed carbonate-rich rocks
8. 2 unmetamorphosed granitoids

Documentation of metamorphic grade in more than one rock association insures that some measure of metamorphic grade is determined for all parts of the study area where sampling has been done. Furthermore, the approach permits a more refined breakdown of metamorphic grade at localities where several associations are present.

Metamorphic Zones

For this project, it is convenient to distinguish "metamorphic zone", a descriptive term for a mappable feature defined for a particular rock association, from metamorphic facies, a particular range of temperature and pressure that is characterized by diagnostic mineral assemblages in a number of rock associations. The range of metamorphic grade in the Watabeag Lake area is represented by 4 zones (Figure 37.2). Boundaries between greenstone, transition and amphibolite zones are determined by mineral assemblages in metabasites. The greenstone zone is divided by a line marking the appearance of biotite in meta-quartzofeldspathic rocks. The upper limit of the greenstone zone (lower limit of the transition zone) is defined by the appearance of hornblende in metabasites containing the assemblage actinolite + epidote + chlorite + albite. Transition zone metabasites contain both actinolite and

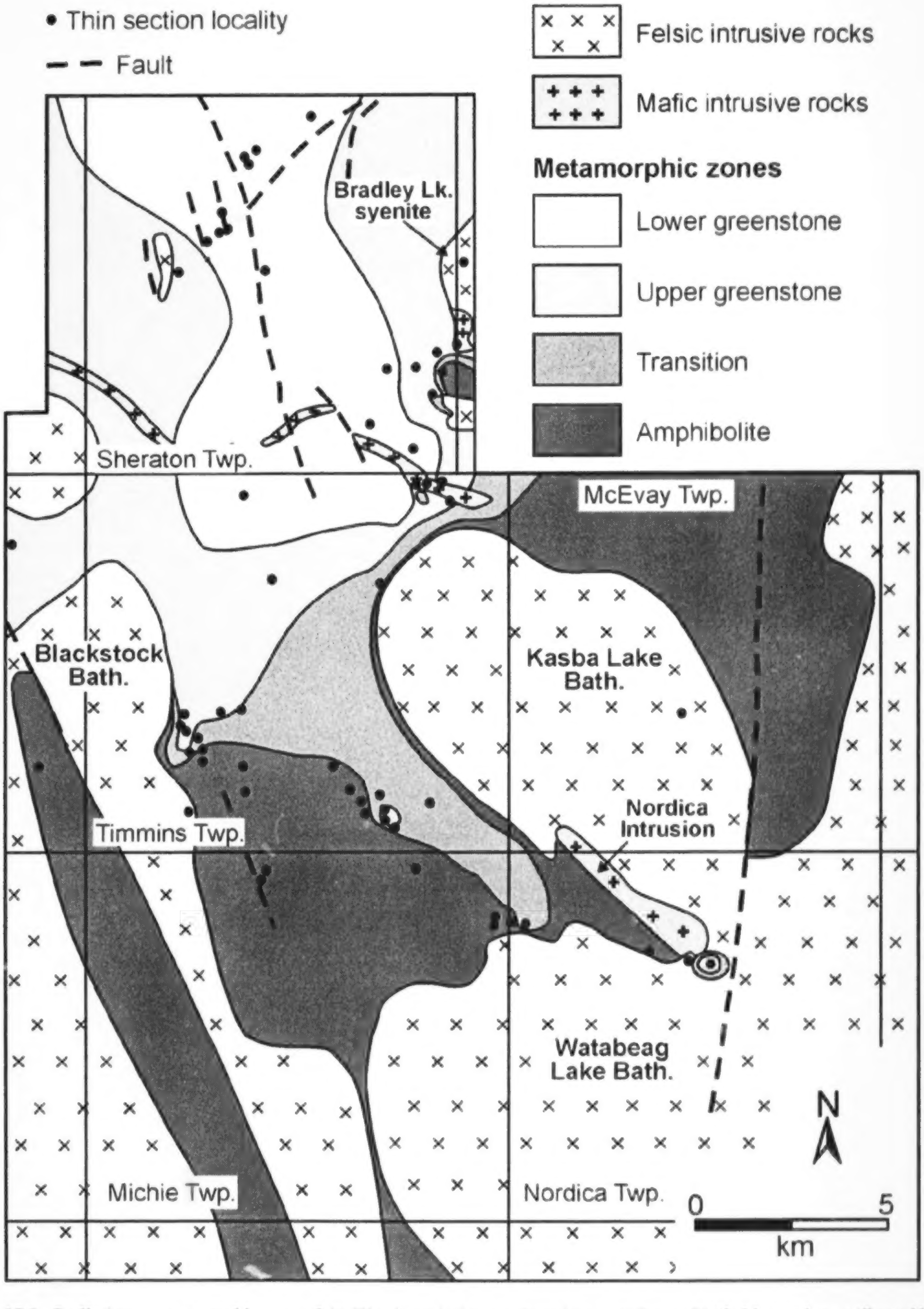
Thin section locality
Fault
Felsic intrusive rocks
Mafic intrusive rocks
Metamorphic zones
Lower greenstone
Upper greenstone
Transition
Amphibolite
Bradley Lk. syenite
Sheraton Twp.
McEvay Twp.
Blackstock Bath.
Kasba Lake Bath.
Timmins Twp.
Nordica Intrusion
Watabeag Lake Bath.
Michie Twp.
Nordica Twp.
N
0
5
km

Figure 37.2. Preliminary metamorphic map of the Watabeag Lake area based on petrology of 103 thin sections collected by C. Vaillancourt (OGS). Rock unit contacts and faults *after* Vaillancourt (2001). Known gold occurrences are in the northeast and southeast corners of Sheraton Township near the lower to upper greenstone zone boundry and a metamorphic "hot spot".

hornblende, commonly along with small amounts of chlorite and/or epidote. Prograde chlorite, actinolite and epidote are absent from amphibolite zone metabasites where the characteristic assemblage is hornblende-calcic plagioclase. In areas where either or both of these rock associations are absent, the mineral assemblages in other associations constrain the position of the isograds. With respect to metamorphic facies, lower and upper greenstone zones correspond approximately to the lower and upper greenschist facies. The greenschist–amphibolite facies boundary occurs within the upper part of the transition zone. The new data extend the area covered by petrographic work 20 km farther south than indicated by Jolly (1978, p.64) and, based on the boundary between the lower and upper greenstone zones, divide his greenschist facies in two. Within the map-scale metamorphic zones, previously unrecognized, kilometre-scale metamorphic anomalies are present. There are 2 occurrences of high metamorphic grade rocks within low metamorphic grade rocks and 2 low metamorphic grade anomalies in high metamorphic grade rocks (*see* Figure 37.2). These metamorphic zone boundaries and metamorphic anomalies are relevant to gold exploration because they may correspond to sites where hydrothermal fluid and heat flow were anomalously high.

Detailed discussion of the metamorphic events that have occurred in the study area and of likely heat sources is beyond the scope of this brief report. There is sufficient evidence, however, to indicate that, as observed in the Timmins area pilot study (Thompson 2002), the metamorphic pattern is the product of a long duration (tens of millions of years) regional metamorphic event that was punctuated by short duration (hundreds of thousands of years) contact metamorphic events related to individual granitoid intrusions. It is likely that at least some components of the batholiths are older than the regional metamorphic event, perhaps similar in age to the metavolcanic rocks. As is the case in most metamorphic terranes, both regional metamorphism and a significant part of the plutonism are closely linked to the deformation history of the belt. White mica and white mica-chlorite aggregates interpreted to be pseudomorphs after andalusite (Vaillancourt 2001; this study) are consistent with Jolly's (1978) regional data indicating metamorphic events are of the low pressure type. That is, anomalously high geothermal gradients (>45 C/km) prevailed during peak metamorphic conditions and post-metamorphic uplift and erosion of medium-grade rocks did not exceed 14 km.

Metamorphism and Deformation

Metamorphic zone boundaries crosscut the major structures mapped by Vaillancourt (2001). Metamorphic textures indicate that metamorphic grade increased during the main phases of ductile deformation and that peak metamorphic conditions outlasted the deformation events. For example, isograds are discordant with respect to east-striking foliations and deformation zones in the southeast corner of Sheraton Township and with respect to the north-northwest-striking foliations and major folds in Timmins Township. A major fault occurs in the lower greenstone zone in Sheraton Township and another fault is close to a low metamorphic grade anomaly near the north edge of the Watabeag Lake batholith (*see* Figure 37.2). The latter spatial relationship suggests that these structures may have been conduits for hydrothermal fluids some time after peak metamorphic conditions had waned and exhumation and cooling of the terrane was in progress. The upper limit of the lowest metamorphic grade zone trends east across the strike of the fault in Sheraton Township and the high metamorphic grade anomaly in the southeast corner of the township occurs within east-striking deformation zones. Major structures in the area have the potential to be conduits for both hot and cold fluids (relative to the background thermal regime) at different times during evolution of the greenstone belt.

Metamorphism and Plutonism

Metamorphism is assumed to be caused by heat from cooling granitic magma in orogenic terranes with abundant granitoid plutons. Contact metamorphism has occurred in the Watabeag Lake area, however, observations made in other gold-bearing, Archean, low pressure, metamorphic terranes (e.g., Thompson et al. 1995; Thompson 2002) has shown that granitoids may be too old, too young or of insufficient volume to have been responsible for regional metamorphism. Petrographic observations (Vaillancourt 2001; this study) confirm that mafic and ultramafic intrusions other than diabase dikes are metamorphosed. The discordance between the biotite isograd (lower–upper greenstone zone boundary) and mafic intrusions in Sheraton Township (*see* Figure 37.2) is consistent with a pre-metamorphic age for intrusion of these rocks. It is possible, however, that contact metamorphism occurred immediately adjacent to these bodies at the time of intrusion. The anomalous transition zone assemblage that occurs near the metamorphosed mafic intrusion in the northeast corner of Timmins Township (*see* Figure 37.2) may be a relict contact effect that has survived greenstone zone grade regional metamorphism. This suggests that gold mineralization and associated alteration related to mafic plutonism were metamorphosed and deformed along with the intrusions.

Of the 6 thin sections from felsic intrusive rocks, 2 are metamorphosed in the lower greenstone zone (biotite not stable) and 2 in the upper greenstone zone or higher (biotite stable). Two of the thin sections collected from the Bradley Lake syenite and the Blackstock batholith were not metamorphosed. At this time, Vaillancourt's (2001) observation of metamorphic hornblende in the metamorphosed mafic intrusion adjacent to the southwest contact of the Bradley Lake syenite is the only evidence of narrow contact aureoles around these plutons. Two low metamorphic grade (biotite not stable) metagranitoid samples are from localities east and south of McEvay Township. It is not possible to determine if chloritization of biotite and growth of epidote in these samples is related to a regional metamorphic event or to post-peak retrograde metamorphism along a fault. Of the 2 felsic granitoid samples metamorphosed within the stability field of biotite, one is a metatonalite phase of the mafic intrusion located in the southeast corner of Sheraton Township and the other occurs in the Kasba batholith. The former is consistent with metamorphic zones as defined in other rock associations, but the latter is in the middle of the Kasba batholith. These few samples are important with respect to the relative timing of metamorphism and plutonism.

As presently interpreted (*see* Figure 37.2), the thin amphibolite zone rimming the Kasba batholith implies contact metamorphism of regional greenstone zone (greenschist facies) rocks by the batholith. In fact, there are no amphibolite zone samples to support this interpretation. The current version of the metamorphic map is an attempt to rationalize the new metamorphic data with the regional configuration of the amphibolite zone as inferred by Jolly (1978). If the metagranitoid sample from the Kasba batholith is representative of the whole intrusion, then it is possible that the batholith predates the isograd pattern. In this case, the transition–amphibolite zone boundary would transect the batholith. Further sampling and petrography is required to address this problem.

Metamorphism and Mineralization

METAMORPHIC ZONE BOUNDARIES (ISOGRADS)

As noted in the introduction, the boundary between lower and upper greenstone zones, and the transition from greenstone to amphibolite zone are considered favourable for gold exploration in Western Australia (Mikucki and Roberts 2003; Hall 1998), the Red Lake greenstone belt (Thompson, in press), the Timmins gold camp (Thompson 2002) and the Yellowknife greenstone belt (P.H. Thompson, unpublished data, 2003). In the study area, there is a known gold occurrence near the boundary between the lower and upper greenstone zones in the southeast corner of Sheraton Township (*see* Figure 37.2). Gold is associated with volcanic-associated massive sulphide mineralization (Cross Lake occurrence, Vaillancourt 2001) near the west limit of the lowest grade metamorphic zone. Mapping of isograds has the potential to be a useful exploration tool for gold mineralization in the area. Isograds are indicators for gold because they formed during metamorphic mineral reactions that either consumed or produced significant volumes of fluid. Furthermore, fluid content and permeability of the rocks is relatively high near isograds at this time and the mineralogical transformation of the rocks provides opportunities for mobilization of gold tied up in mineral lattices.

METAMORPHIC ANOMALIES

Anomalously high metamorphic grade rocks occur at 2 localities (*see* Figure 37.2) within the upper greenstone zone. Anomalously low metamorphic grade rocks occur in the transition zone in Timmins Township and in what is inferred to be an amphibolite zone in Nordica Township (*see* Figure 37.2). In addition to those associated with "hot" and "cold" spots, steep metamorphic gradients (closely spaced isograds) are inferred from the available data to occur close to the Blackstock and Kasba batholiths. Atypical closely spaced isograds occur within the map-scale metamorphic zonation or around smaller scale nodes of relatively high and low metamorphic grades. These close-spaced isograds are consistent with higher than normal magnitudes of heat and are considered to have resulted from hydrothermal fluid flow. Focussing of fluid and heat flow within planar and linear conduits can occur along deformation zones, fold noses and in zones of fractured rocks that develop during ductile deformation near contacts between rocks of differing competencies. Alternatively, a high-grade metamorphic anomaly may be related to a buried intrusion. Low metamorphic grade anomalies can develop in and around structural or litho-structural conduits when concentrated fluid flow occurs for a sufficiently long time after the metamorphic and plutonic rocks have begun to cool. All of the environments likely to have produced metamorphic anomalies in the study area are potentially conducive to mobilization, transport and deposition of gold.

METAMORPHISM AND LOGGING OF ALTERATION

Vaillancourt (2001) concluded that there is potential for volcanic-associated massive sulphide and magmatic nickel-copper-platinum group element mineralization in the Watabeag Lake area. Because the metavolcanic rocks and associated mafic to ultramafic intrusions are older than the metamorphic events, their coeval mineral deposits and related alteration will be metamorphosed. One of the fundamental concepts of metamorphic petrology is that, aside from gain and/or loss of relatively small amounts of water and carbon dioxide, the bulk composition of the metamorphic rocks does not change. This means that, during metamorphism, the mineralogy of the various types of alteration associated with base metal deposits will change with time, but the distinctive chemistry of these rocks will remain essentially the same. Where metamorphic gradients are present, each particular type of alteration will develop its own set of metamorphic zones. For example, "chlorite-sericite" alteration may change to "biotite alteration". Documentation and interpretation of the metamorphic setting of base metal mineralization in metamorphic terranes assists diamond-drill core loggers in identifying the nature and distribution of pre-metamorphic alteration. These principles apply as well to logging of alteration related to pre-metamorphic, synvolcanic gold deposits and to pre-metamorphic intrusion-related gold.

CONCLUSIONS AND SUGGESTIONS FOR EXPLORATION

The results from this small part of the area to be covered by the Discover Abitibi Metamorphic Subproject illustrates the potential utility of mapping metamorphic zones and anomalies in the Timmins–Kirkland Lake area as part of a gold exploration program. Once metamorphic anomalies are outlined by reconnaissance petrography as at Timmins (*see* Figure 37.1) and Watabeag Lake (*see* Figure 37.2), more detailed work will improve definition of the metamorphic features and determine if they are products of buried intrusions or of high fluid flow along structural and litho-structural conduits.

This study highlights areas where data density is insufficient to apply metamorphic exploration tools. For example, there are no OGS thin sections in and around the Paymaster and Preston gold mines (*see* Figure 37.1). Access to thin sections in company files or to diamond-drill core may solve this problem.

Metamorphic features are indicators for gold in their own right, but it is likely that the full potential of metamorphic data and concepts will be realized only when integration with other data sets has been carried out.

The coincidence of the high-grade metamorphic anomaly, east-striking deformation zones, and intrusive rocks, together with proximity to the upper limit of the lower greenstone zone and known gold mineralization, makes the southeast corner of Sheraton Township the highest priority target area in the Watabeag Lake area.

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38. Project Unit 00-011. Volcanology and Economic Potential of Komatiitic Rocks in the Shaw Dome Area

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INTRODUCTION

This project is an affiliated OGS project designed to complement the Discover Abitibi Greenstone Architecture Project (Ayer, Thurston et al., this volume) by focussing on nickel-copper-platinum group element (PGE) mineralization in the Shaw Dome area in the vicinity of the Langmuir, Hart, McWatters and Redstone deposits (Figure 38.1). This project represents an in-kind OGS contribution, which is part of the Ontario Geological Survey core program. This project is also a multi-year study to re-evaluate the geology and the mineral potential of the Shaw Dome area in the central part of the Abitibi greenstone belt. Bedrock mapping of Shaw, Eldorado and Adams townships in 2003 (Hall and Houlé, this volume) follows the bedrock mapping of Deloro Township in 2002 (Hall, MacDonald and Dinel 2003). The Shaw Dome area is one of the most complex and economically significant parts of the Abitibi greenstone belt. The OGS products from this project will include 1:20 000 scale bedrock geology maps of Shaw, Adams, Eldorado, Carman and Langmuir townships; and detailed cross-sections illustrating critical stratigraphic relationships across the Shaw Dome.

Nickel-copper-(PGE) sulphide mineralization associated with komatiitic rocks (komatiites and komatiitic basalts) in Archean and Proterozoic greenstone belts are an important part of the broader category of magmatic Ni-Cu-PGE mineralization. Although komatiitic basalts and komatiites occur in several greenstone belts worldwide, the majority of known Ni-Cu-(PGE) deposits occur in only a few of these belts, including the Abitibi and Cape Smith belts of Canada, the Norseman–Wiluna and Forrestania belts of Western Australia, the Bindura–Shamva and Shangani–Filabusi belts of Zimbabwe, the Crixas and Minas Gerais belts in Brazil, and the Pechenga belt in Russia. Several of the Ni-Cu-(PGE) deposits in the Abitibi greenstone belt occur in the Shaw Dome area, including the Langmuir #1, Langmuir #2, Redstone, McWatters, Hart, and Galata deposits and/or showings (*see* Figure 38.1). Komatiite-hosted deposits contain a variety of mineralization types (Lesher and Keays 2002), which may be subdivided into 3 broad genetic categories: magmatic, hydrothermal mobilized and tectonically mobilized. Each of these categories may be subdivided into several types and subtypes (Lesher and Keays 2002; *see also* Vaillancourt et al. 2003) (see Table 38.1). The most favourable Ni-Cu-(PGE) mineralization types in the Shaw Dome area, in order of economic potential, are stratiform basal or footwall (Type I: Kambalda-type), stratabound internal (Type II: Mt. Keith type) and stratiform internal (Type III: "reef-type").

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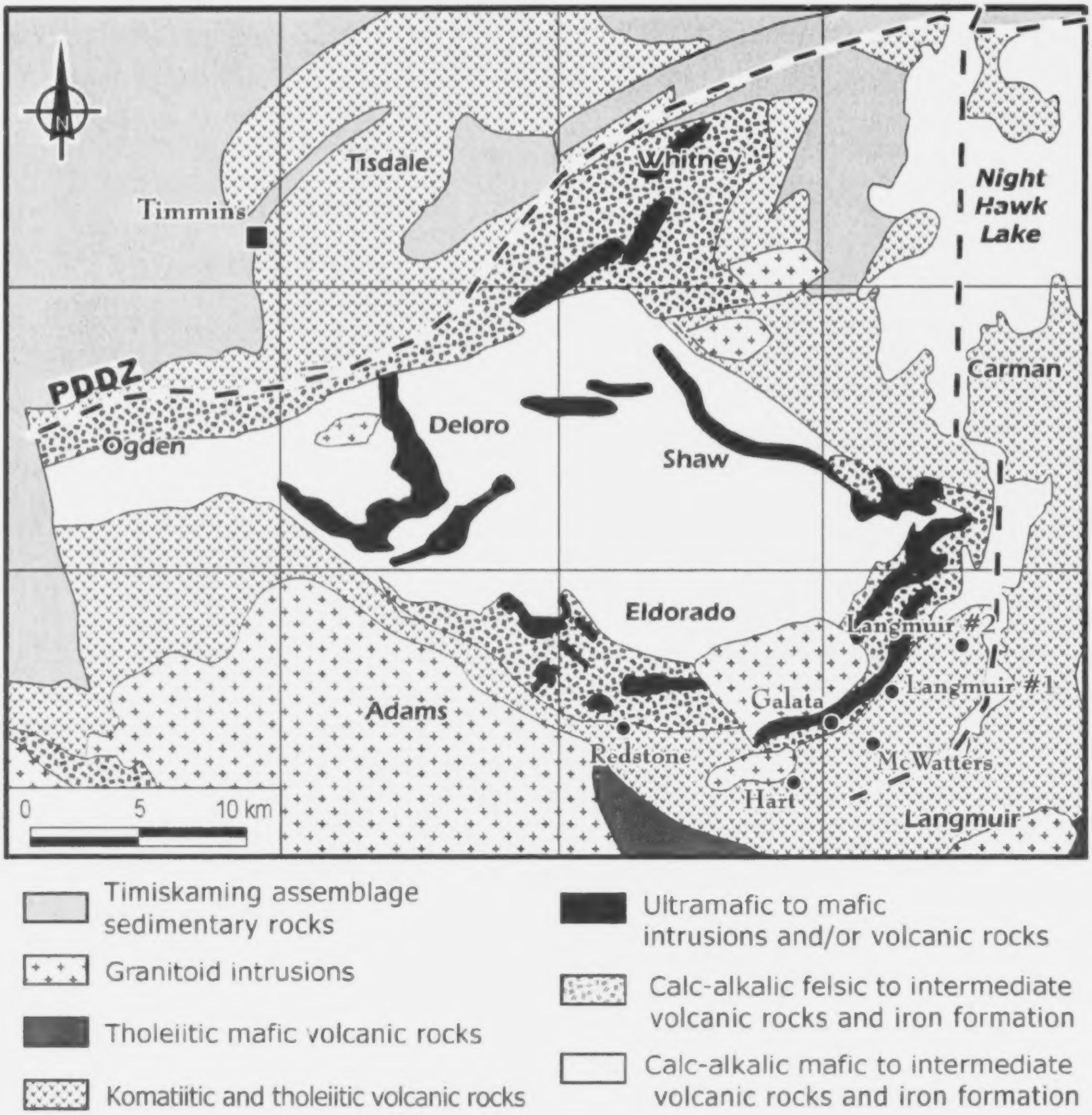
The goals of this project are three-fold:

1. to evaluate the subvolcanic–volcanic architecture of the ultramafic rocks of the Shaw Dome
2. to evaluate the Ni-Cu-(PGE) mineral potential of the komatiitic rocks
3. to better understand the stratigraphic and structural configuration of the ultramafic rocks in the context of the Shaw Dome

Geophysical and diamond-drill hole data are being used to aid in the extrapolation of geological contacts across the many large areas obscured by overburden.


N
Tisdale
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Night Hawk Lake
PDDZ
Ogden
Deloro
Shaw
Carman
Eldorado
Langmuir #2
Langmuir #1
Galata
Adams
Redstone
McWatters
Hart
Langmuir
0 5 10 km
Timiskaming assemblage sedimentary rocks
Granitoid intrusions
Tholeiitic mafic volcanic rocks
Komatiitic and tholeiitic volcanic rocks
Ultramafic to mafic intrusions and/or volcanic rocks
Calc-alkalic felsic to intermediate volcanic rocks and iron formation
Calc-alkalic mafic to intermediate volcanic rocks and iron formation

Figure 38.1. Simplified geological map of the Shaw Dome area (*modified from* Pyke (1982) and Larson (1996)).

Table 38.1. Simplified classification of mineralization types in komatiite-associated magmatic Ni-Cu-PGE deposits (*modified from* Lesher and Keays 2002).

Origin	**Type**		
Type	**I** **Stratiform Basal or Footwall**	**II** **Stratabound Internal**	**III** **Stratiform "Reef-style"**
Sulphide distribution	At or near the bases of komatiitic peridotite or komatiitic dunite units	Within komatiitic peridotite or dunite units	At or near contact between lower ultramafic cumulate zones and upper mafic zones
Sulphide textures	Massive, net-texture, disseminated	Disseminated, interstitial	Disseminated
Timing and paragenesis	Segregated prior to or during emplacement	Segregated during crystallization of cumulate host rock	Segregated during final stages of crystallization of host rock
Examples in Shaw Dome	Langmuir #1, Langmuir #2, McWatters, Hart, Redstone	Not identified	Not identified
Examples elsewhere in the Abitibi greenstone belt	Alexo, Dundonald	Bannockburn, Dumont	Fred's Flow, Boston Creek Sill

METHODOLOGY

Selection Criteria for the Area

As recognized by previous workers, physical volcanology is the most important factor controlling the occurrence of Ni-Cu-(PGE) in komatiitic rocks (Lesher, Arndt and Groves 1984; Lesher 1989; Hill et al. 1990; Lesher and Campbell 1993; Hill et al. 1995; Barnes et al. 1999). Geochemical studies of komatiites in Western Australia (Lesher 1989; Lesher and Stone 1996) and the Abitibi greenstone belt (Sproule et al. 2003) indicate that most komatiitic rocks are sulphide undersaturated and were generated from fertile sources capable of generating Ni-Cu-PGE deposits, regardless of magma type, age, or location.

The main focus of this project is to acquire a better understanding of the physical volcanology and to assess the mineral potential of the komatiitic rocks in the Shaw Dome area. This will be achieved by developing metallogenic, stratigraphic and tectonic models of the Shaw Dome area through mapping at township scale as well as more detailed mapping in selected areas identified during the course of the mapping. The detailed mapping (mine property to outcrop scale) will focus on features that give insight into komatiitic volcanology and emplacement mechanisms. The ultimate goal of this work has been to define new exploration tools for Ni-Cu-PGE mineralization. Selection criteria used to identify areas for detailed mapping include

1. presence of large quantity and good quality of surface exposure and/or excellent preservation of the geological relationships in a specific area
2. availability of previous work in this area by mining companies and/or prospectors
3. presence of critical geological relationships to constrain the mineral potential and the stratigraphy in this area
4. ease of access to the field area, allowing several work days in the same area

Field Investigations

Field investigations for this subproject will involve at least 2 field seasons. The first year of data collection was performed by 3 two-person crews between June 2003 and August 2003. The work was integrated within regular township-scale mapping as part of the Ontario Geological Survey core program. The principal aims of this field work are to complete reconnaissance work and to begin detailed investigations in Shaw, Eldorado and Adams townships. The second year of investigation will focus on Langmuir and Carman townships. The priority will be to focus on surface outcrops, supplemented with diamond-drill core investigations where possible, particularly in areas where outcrop is poor. Data collection is aimed at improved understanding of the volcanology, stratigraphy and structure of those rocks, through

1. data related to the *overall outcrop* expression of lithologic units and their spatial relationships (e.g., number of units, homogeneity, etc.)
2. data related to *specific units* including rock type (e.g., komatiitic basalt, komatiite, komatiitic peridotite, komatiitic dunite); texture (e.g., grain size, aphyric or spinifex or cumulate, crystal habit, proportion of olivine, etc.); structure or morphology (e.g., magmatic layering, polyhedral jointing, pillows, hyaloclastite, top indicators, vesicles, amygdules, foliation, shearing, etc.); mineralogy (e.g., olivine, pyroxene, chromite, serpentine, etc.); and flow or unit characteristics (e.g., thickness, degree of differentiation, degree of olivine accumulation, transgressive contacts, etc.)
3. data related to *footwall and hanging wall lithologies* (e.g., iron formations, clastic sedimentary rocks, coherent or fragmental volcanic rocks, etc.)
4. data related to any kind of *mineralization* (e.g., massive sulphides, net-textured sulphides, disseminated sulphides, etc.)
5. data related to *alteration* (e.g., serpentine, talc-carbonate, etc.) and *intensity* (e.g., weak, moderate, intense, pervasive)
6. data related to stratigraphy (e.g., facing determinations) and acquiring new samples for U/Pb geochronology (funded by the Discover Abitibi Greenstone Architecture Project) to establish the absolute ages of the economically important units
7. data related to structure (e.g., by field observations and interpretation using all available geophysical data) including computer-generated geophysical inversions to test structural interpretations at depth and aid in development of realistic cross-sections (funded in part by the Discover Abitibi Greenstone Architecture Project)

IMPLICATIONS FOR NICKEL-COPPER-PLATINUM GROUP ELEMENT MINERALIZATION

The physical volcanology of komatiites is the single most important parameter in assessing the mineral potential of komatiites (Lesher, Arndt and Groves 1984; Lesher 1989; Hill et al. 1990; Lesher and Campbell 1993; Hill et al. 1995; Barnes et al. 1999). The nature of the volcanological processes, the architecture of komatiite flow fields, and the nature of flow advance mechanisms (i.e., inflation: *see* Hon et al. (1994) and Self, Thordarson and Keszthelyi (1997)) are topics of current debate (e.g., Dann 2000; Hill 2001; Beresford et al. 2002; Lesher and Keays 2002). The number and size of Ni-Cu-(PGE) deposits are much greater in the Norseman-Wiluna greenstone belt of Western Australia than in the Abitibi greenstone belt of Ontario–Quebec. These differences have been attributed to differences in their tectonic, stratigraphic, and volcanic settings (Lesher and Keays 2002; Sproule et al. 2002). However, more detailed studies of the physical volcanology and stratigraphy of komatiitic rocks in the Abitibi greenstone belt will help to constrain the above parameters and facilitate assessment of their economic potential. A better understanding of the physical volcanology of komatiites will also provide critical information of the genesis of komatiite-associated Ni-Cu-(PGE) deposits, of the nature of volcanism on the young Earth and of the stratigraphy and structure of Archean and Proterozoic greenstone belts.

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39. Discover Abitibi. Base Metal Subproject 1. Volcanogenic Massive Sulphide Mineralization in the Kamiskotia Area

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INTRODUCTION

The aim of this subproject is to understand the stratigraphy, volcanic facies and alteration associated with base-metal mineralization in the Kamiskotia area (Abitibi greenstone belt, Timmins region). In the initial field season, the southern of the 2 selected corridors (Ayer, Thurston et al., this volume, Figure 32.1, Area 2) were mapped at 1:10 000 scale (see previous mapping by Middleton 1975; Vaillancourt, Pickett and Dinel 2001; Hall and Smith 2002). The bedrock mapping corridors are located mainly in Godfrey and Turnbull townships (Figure 39.1) and include the Genex VMS deposit. A key goal has been to establish a stratigraphic and volcanic facies framework for the largely rhyolitic Archean volcanic succession that hosts the base-metal deposits. The earlier mapping had suggested that the succession was largely eastward younging (Middleton 1975), with way-up determinations based largely upon pillow shape and packing in mafic pillowed metavolcanic units. The present study has focussed on the felsic volcaniclastic rocks, with top determinations mainly obtained from graded sediment-gravity-flow units with sharp, often erosional bases. This has allowed development of a more comprehensive structural and stratigraphic model for the area. An age determination of 2705 Ma by Barrie and Davis (1990) places the rhyolites, in the western part of the map area, in the Tisdale assemblage (2703 to 2710 Ma). However, at a regional scale (Ayer and Trowell, 1998; Ayer et al. 2002), the map of this region shows unsubdivided rhyolitic units. Regional considerations indicate that the basaltic rocks in southern Carscallen Township (Hall and Smith 2002) are part of the Kidd–Munro assemblage of Ayer et al. (2002). Thus, the Kamiskotia stratigraphy in this area overlies the slightly older Kidd–Munro assemblage.

RESULTS

In Godfrey and northern Bristol townships, the rhyolitic complex dips steeply westward and youngs to the east. The rocks dip and young to the west in Turnbull Township and dip and young to the southwest in northern Carscallen Township. Thus, a major north-northwest-trending, antiformal axis in the Godfrey–Turnbull township boundary area must separate these opposite-facing successions (*see* Figure 39.1). The volcanic succession is intruded by microdiorite and andesite of the Kamiskotia Intrusive Complex (Middleton 1975), and is cut by a number of broadly east-striking faults. The most important of these faults extends west from Aconda Lake (*see* Figure 39.1; Aconda Lake fault: ALF) and offsets north-northwest-trending Proterozoic diabase dikes with an apparent dextral displacement of 0.5 km. Displacement within the Archean succession appears to have a similar sense, but is harder to quantify.

The west- and southwest-facing succession is best exposed in northern Carscallen Township (section A–A′: *see* Figure 39.1) and in Turnbull Township north of the ALF (B–B′: *see* Figure 39.1). Both sections

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Ontario Geological Survey, Open File Report 6120, p.39-1 to 39-4.

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include two lithologically distinct units that consist of massive rhyolite and related volcaniclastic rocks. The presence of these units enables stratigraphic correlation between the two areas. The lower unit (*see* Figure 39.1; unit 1) consists of fine quartz- and feldspar-phyric to aphyric, thinly flow-banded rhyolite, intercalated with and overlain by lithic lapilli tuff. The latter is particularly easy to recognize, with very distinct, pale, often texturally diverse lithic lapilli and more ductile, dark, originally glassy fragments in a dark, sericite-rich matrix. In Carscallen Township, unit 1 encloses a lens of basaltic pillow lava. The overlying unit 2 consists of coarse quartz- and feldspar-phyric rhyolite and tuff breccia or lapilli tuff in which matrix and clasts are characteristically hard to distinguish. In Carscallen Township, a crystal-rich lapilli tuff or tuff unit, locally rich in altered tuff intraclasts, occurs below unit 1. However, the Turnbull Township section (B–B′: *see* Figure 39.1) is cut out by intrusive rocks at this level. The area between the two sections (south Turnbull Township) has less exposure and seems to be more structurally complex, but appears to consist mainly of rocks belonging to unit 2. This is the approximate area from which the geochronological sample of Barrie and Davis (1990) was taken.

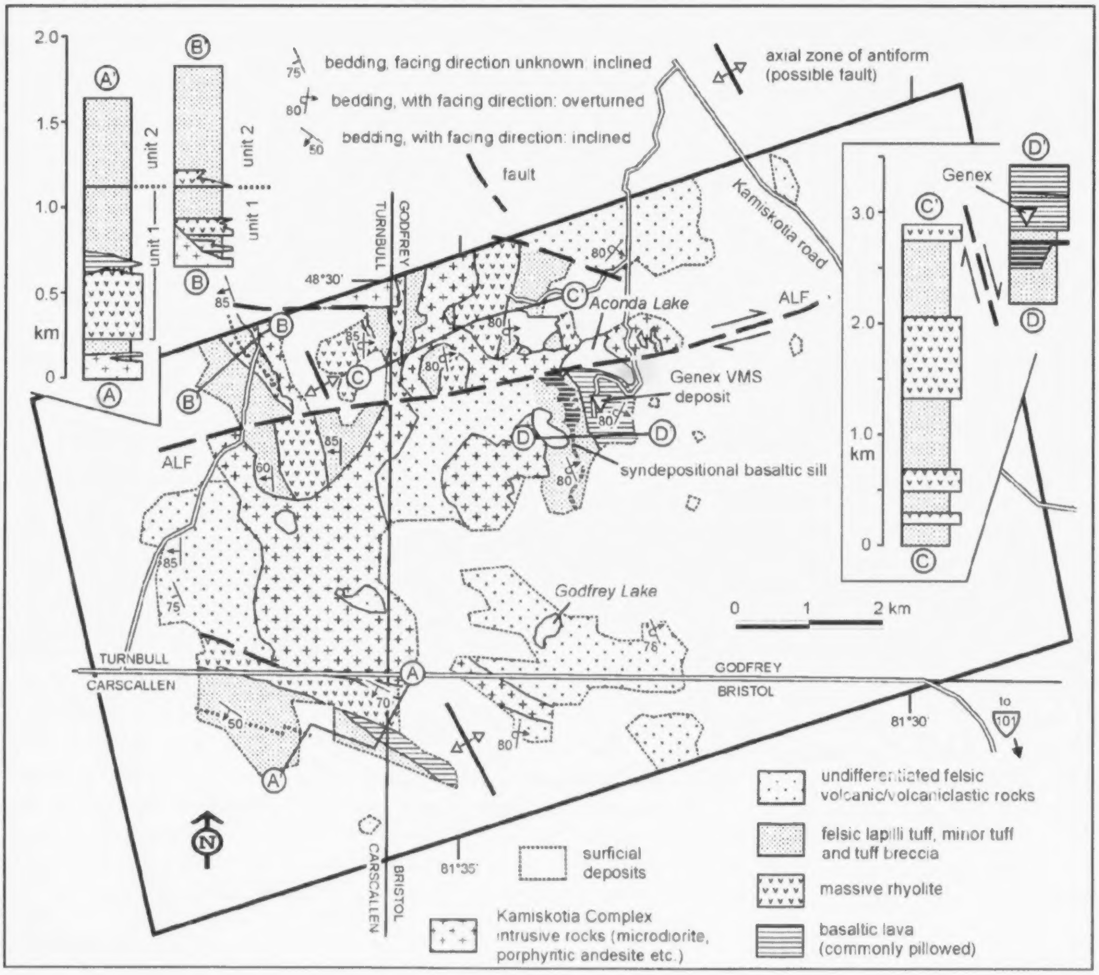
2.0
1.5
1.0
0.5
km
0
A′
A
B′
B
unit 2
unit 1
bedding, facing direction unknown: inclined
bedding, with facing direction: overturned
bedding, with facing direction: inclined
fault
axial zone of antiform (possible fault)
TURNBULL
GODFREY
48°30′
Aconda Lake
Kamiskotia road
ALF
Genex VMS deposit
syndepositional basaltic sill
Godfrey Lake
0 1 2 km
TURNBULL
CARSCALLEN
GODFREY
BRISTOL
81°30′
to 101
81°35′
CARSCALLEN
BRISTOL
C′
C
D′
D
Genex
3.0
2.0
1.0
km
0
undifferentiated felsic volcanic/volcaniclastic rocks
felsic lapilli tuff, minor tuff and tuff breccia
massive rhyolite
basaltic lava (commonly pillowed)
surficial deposits
Kamiskotia Complex intrusive rocks (microdiorite, porphyritic andesite etc.)
N

Figure 39.1. Sketch geological map of Kamiskotia area Base Metal Subproject Area 2, with selected stratigraphic columns. For clarity, Kamiskotia Complex intrusive rocks have been omitted in section C–C′. ALF = Aconda Lake fault. The contact between units 1 and 2 in Turnbull and Carscallen townships is marked by a dotted line on the map and in sections A–A′ and B–B′.

The east-facing succession is most consistently exposed in northern Godfrey Township, to the north of the ALF. Here, a 3 km thick succession (section C–C′; *see* Figure 39.1) consists of intervals of massive quartz or feldspar-phyric rhyolite from 100 to 700 m thick, alternating with similar thicknesses of compositionally similar, highly sericitized, commonly bedded lapilli tuff. These rocks are extensively intruded by microdiorite in close proximity to the ALF.

South of the ALF, in the area of the Genex deposit (section D–D′; *see* Figure 39.1), a well-exposed, 1.25 km thick section consists of approximately 600 m of generally fine felsic lapilli tuff (clasts typically <1 cm), with minor tuff breccia and minor massive rhyolite. The overlying basaltic pillow lava-dominated succession hosts the Genex VMS deposit (Hocker et al., this volume). A shallow-level, syndepositional basalt sill that can be intermittently traced for almost 2 km along strike intrudes the upper part of the felsic succession. Within 700 m of the ALF, in the area immediately beneath the base-metal deposit, the sill is up to 250 m thick and includes 100 m scale screens or rafts of felsic lapilli tuff, which are intimately invaded by the intruding basalt. Farther south, the sill thins to 25 to 30 m and exhibits textures indicating intrusion into wet, unconsolidated sediment (peperite) at its base and top.

The east-facing succession in southern Godfrey and northern Bristol townships appears to be lithologically similar to the successions located farther north, but marker units that would allow correlation have not been identified as yet. Finally, it should be noted that distinctive units present in the west-facing succession have not been identified in the east-facing succession and vice-versa. There appears to be no simple repetition of stratigraphy across the antiform axis, and it seems likely that the core of the structure is faulted, with the possibility of significant age difference between the two successions. A strong, broadly east-striking tectonic fabric is developed throughout the area. This is typically a spaced cleavage, with associated north-south flattening of pillows and felsic clasts. Locally developed, relatively small-scale (up to 500 m wavelength), generally low-amplitude folds with east-trending axial planes are probably related to this phase of deformation. Earlier fabrics that could be related to the larger north-northwest-trending antiform were not identified.

In order to constrain the age of mineralization, samples of rhyolite and volcaniclastic rocks have been collected for U/Pb geochronology from the footwall of the Genex deposit in Area 2. In addition, geochronological samples were taken from units associated with the Half-Moon Lake and Kam-Kotia deposits further to the north, in subproject Area 1 (scheduled to be mapped in 2004). An age determination on the Genex deposit succession will also allow comparison with the available age from the western succession in Turnbull Township.

DISCUSSION

The volcanic succession is dominated by rhyolite lavas (and/or shallow-level intrusions) and rhyolitic lapilli tuffs. In the latter, the lack of vesicular fragments and intimate association with massive, commonly flow-banded rhyolite suggest primary fragmentation by quench (hyaloclastite) or autoclastic (flow-breccia) processes, rather than pyroclastic eruptions (*see*, for example, Fisher and Schmincke 1984). Identification of graded, often sharp-based units in many volcaniclastic intervals indicates redeposition by sediment gravity flows. Sericitic alteration of felsic volcaniclastic rocks is ubiquitous, but mineralization-related alteration zones appear to be confined to the immediate area of the Genex deposit (Hocker et al., this volume). In the footwall of the Genex deposit, marked thickening of the syndepositional sill towards the ALF suggests possible synvolcanic movement on that structure. The overlying pillow lavas appear to be confined to the south side of the fault, which also seems to have controlled later intrusion of microdiorite. The ALF may have had an early history as the northern boundary fault of a small, extensional half-graben, providing a conduit for basaltic magma and mineralizing fluids into that eruptive and depositional centre.

As previously indicated herein, the Kamiskotia area rhyolites reported on here stratigraphically overlie Kidd–Munro assemblage units (ca. 2718 to 2710 Ma) in Carscallen Township (Hall and Smith 2002). The structural interpretation presented here places the Tisdale assemblage age rhyolite reported by Barrie and Davis (1990) on the western flank of a major antiformal structure. However, at this stage, we cannot be certain that all Kamiskotia area rhyolites described here are of Tisdale assemblage age.

Field work in Area 2 was in progress at the time of writing, and conclusions may change as mapping proceeds, and as diamond-drill core and geophysical data are compiled to supplement the outcrop data. It is also hoped that petrographic and lithogeochemical work will provide a further basis for correlation within the rhyolitic complex.

EXPLORATION SUGGESTIONS

Initial field work suggests that synvolcanic extensional faulting may have played an important role in localizing VMS mineralization within the rhyolitic complex. It is possible that the Genex deposit horizon continues northward along strike, but is offset to the northeast across the ALF. However, given the possibility of early structural control, it may be that mineralization is confined to the south of the ALF, in which case, any further deposits might be found up-section along the trace of the fault. Although relatively restricted alteration haloes such as that associated with the Genex deposit may prove difficult to locate, the identification of further synvolcanic structures may provide a tighter focus for more detailed exploration in key areas.

ACKNOWLEDGMENTS

This work has been funded by the Discover Abitibi Initiative, managed by the Timmins Economic Development Corporation. We have benefited from discussions with local prospectors and mining companies, especially Falconbridge Exploration. Thurston's contribution is in part financed by the Natural Sciences and Engineering Research Council of Canada (NSERC).

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40. Discover Abitibi. Base Metal Subproject 2. Preliminary Assessment of Volcanological Facies, Alteration and Mineralization at the Genex and Canadian Jamieson Deposits, Kamiskotia Area

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INTRODUCTION

The Base Metals Subproject of the Discover Abitibi Initiative is a group of projects aimed at addressing the volcanic facies, lithology, structure and alteration of the Kamiskotia area to establish stratigraphic controls, identify horizons containing base metal mineralization, and define key marker horizons within the Abitibi greenstone belt. Geologic mapping of the Genex and Canadian Jamieson deposits in the Kamiskotia area are part of the Base Metals Subproject.

This report summarizes the preliminary results of the 2003 field season which focussed on the volcanic stratigraphy, alteration history, controls on mineralization and structural deformation in and around the Genex and Canadian Jamieson deposits using volcanic facies and alteration mapping.

The volcanic stratigraphy of the Kamiskotia area has been broadly addressed at a regional scale by Middleton's 1975 map (Middleton 1975) that covers all of Godfrey Township. The Genex deposit itself has been mapped at 1:1000 scale by Legault in 1985 (Legault 1985), but significant advances in research techniques and in the understanding of Archean volcanic-hosted massive sulphide (VHMS) systems creates the need for re-evaluation of the Genex and Canadian Jamieson VHMS deposits.

The Kamiskotia area is a bimodal succession of Archean (2703 to 2715±2 Ma) felsic and mafic volcanic complex with minor associated sedimentary rocks, and several large, multi-phase intrusions (Legault 1985). The region has been strongly deformed and altered, and hosts several VHMS deposits with production ranging in size from the Kam-Kotia deposit (6 million tonnes of ore: Binney and Barrie 1991) to the Genex deposit (242 tonnes of Cu concentrate: Binney and Barrie 1991). Preliminary work by Hocker and Hudak, and Hathway and Thurston (this volume) have shown that the stratigraphy is considerably more deformed and complicated than initially shown by previous mapping (e.g., Middleton 1975).

RESULTS

Genex Deposit

The Genex deposit consists of 2 orebodies (the C-zone and the H-zone) that were mined from 1964 to 1966. Over this time period, approximately 242 tonnes (218 tons) of Cu concentrate containing 21 to 27% Cu were produced (Middleton 1975; Binney and Barrie 1991).

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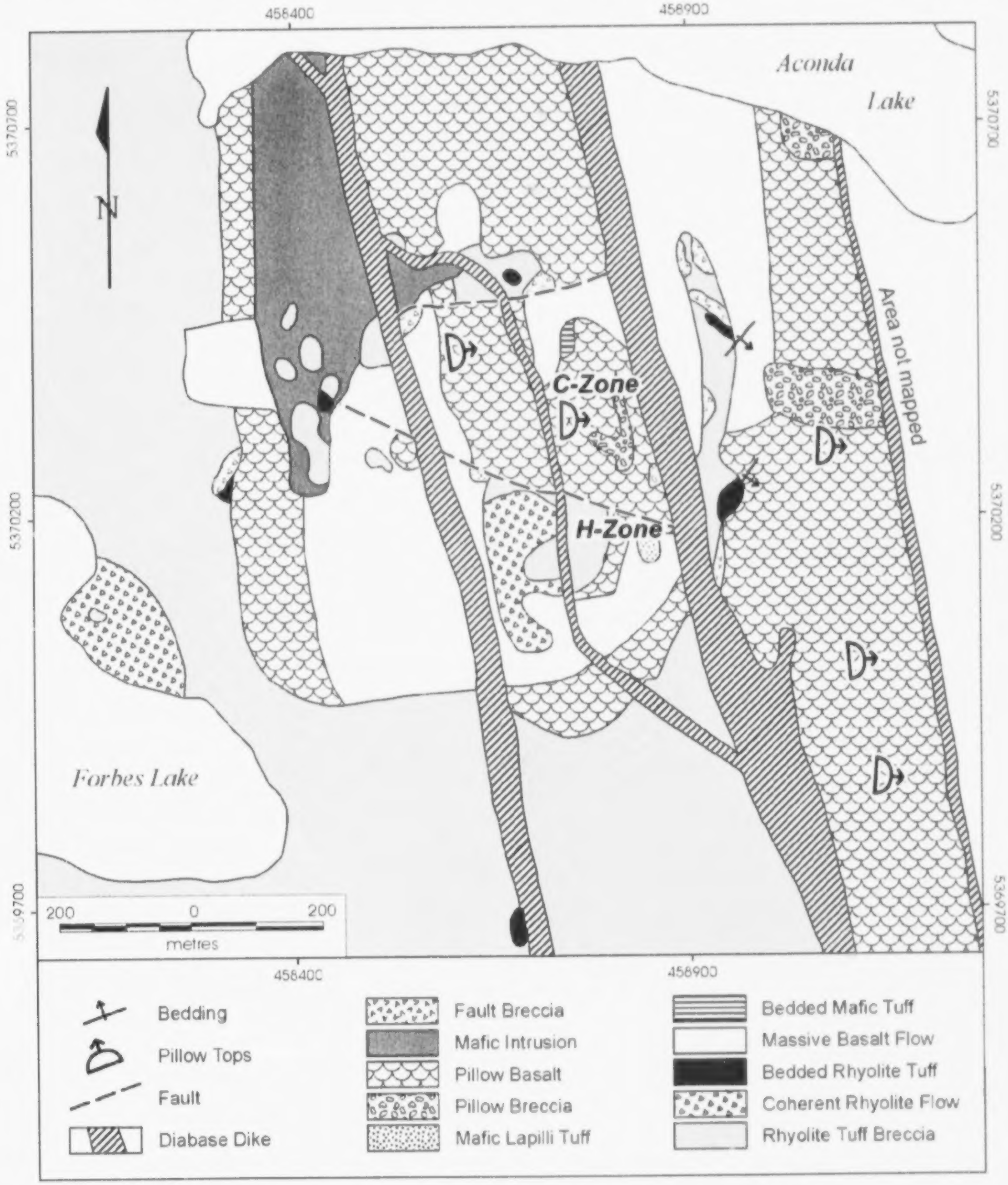
In June to August 2003, 1:1000 scale surface mapping was completed throughout the area bounded by Aconda Lake to the North, Forbes Lake to the west, and the availability of outcrop to the south and east. Selected outcrops were mapped at a scale of 1:100 on a 4 m grid. Mapping shows that the Genex area is a bimodal succession with dominantly mafic metavolcanic pillowed and massive strata and associated felsic tuffs (all volcaniclastic rocks are described using Fisher's 1966 non-genetic classification


458400
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5370700
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N
Aconda Lake
C-Zone
H-Zone
Area not mapped
Forbes Lake
200 0 200
metres
Bedding
Pillow Tops
Fault
Diabase Dike
Fault Breccia
Mafic Intrusion
Pillow Basalt
Pillow Breccia
Mafic Lapilli Tuff
Bedded Mafic Tuff
Massive Basalt Flow
Bedded Rhyolite Tuff
Coherent Rhyolite Flow
Rhyolite Tuff Breccia

Figure 40.1. Preliminary geological sketch map of the Genex deposit, Kamiskotia area.

for volcaniclastic rocks), and flows, mafic tuffs and mafic intrusions (Figure 40.1). The area is also cut by several Proterozoic diabase dikes (Middleton 1975; Legault 1985). Pillow topping indicators, as well as bedding and grading in the felsic units indicate that stratigraphy throughout the field area is uniformly near vertical and east younging.

Both intrusive and extrusive mafic lithologies are present. Extrusive mafic units consist of pillowed and massive flows as well as minor mafic tuffs. Within the pillowed units, there is great variability in pillow size, pillow hyaloclastite thickness, amygdule and vesicle percentage and degree of alteration. Within individual pillow units, there is evidence that the pillows are mantling the paleotopography of the seafloor. Small pillow breccia units and massive basal flow units are also found associated with the pillow flows. The larger massive mafic flows are generally 0 to 15% vesicular. However, due to limited outcrop in some areas, lithologies mapped as massive may in fact be pillowed. Mafic tuffs are found mainly in the transition from pillowed to massive flows, and range from fine-grained tuffs to lapilli tuffs. In the northwest side of the field area, a large mafic to intermediate sill is present. This sill contains xenoliths of felsic breccia. Amoeboid, synvolcanic mafic dikes are also present in a single mafic tuff outcrop in the southwest side of the map area.

Felsic metavolcanic rocks in the Genex area range from felsic tuffs to flows. The felsic tuffs are found in large lens- and block-shaped bodies throughout the area (*see* Figure 40.1). Bedded tuffs are found in 5 discrete lenses in the area and are locally normally graded. Tuff breccias are much more common, and contain lapilli- to block-size fragments that are of the same composition as their matrix. Coherent felsic flows occur dominantly in the south and west boundaries of the field area and commonly exhibit flow banding and *in situ* brecciation.

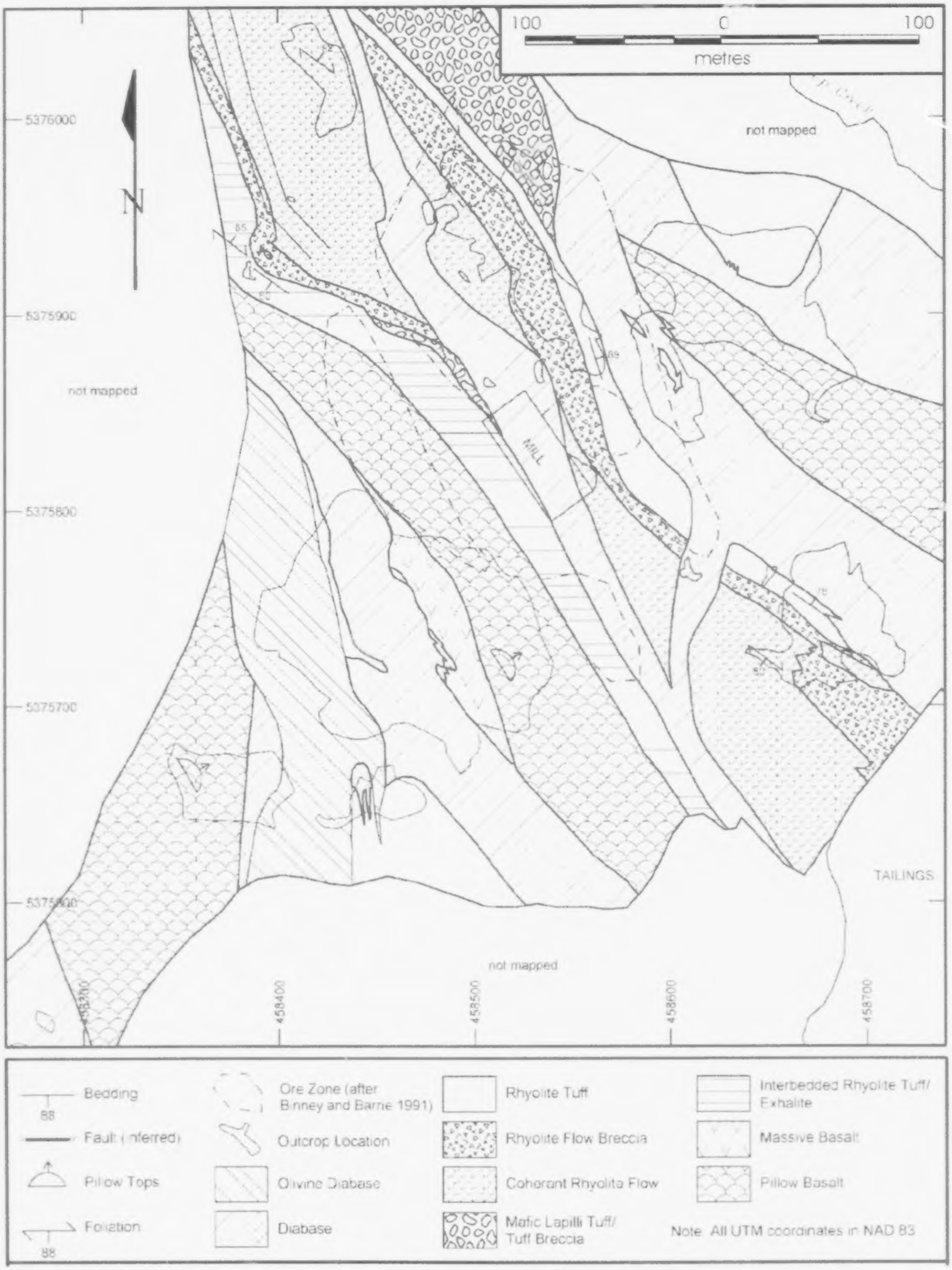
Mineralization in the Genex deposit proper is associated with 2 separate rock types. Mineralization in the C-zone (*see* Figure 40.1) is contained within the matrix of a thin (approximately 0.5 to 3 m wide) pillow breccia located between two pillowed mafic flows. Mineralization in the H-zone is hosted in a felsic lapilli tuff. Numerous trenches in both the mafic and felsic units are also present throughout the area. Trenches following the strike of shear zones are often characterized by black sphalerite.

Throughout the field area, several alteration assemblages are present. Within the mafic units, a chlorite + quartz assemblage is prevalent, whereas, in the felsic units, a quartz + sericite assemblage is prevalent. Locally, epidote + magnetite, epidote + actinolite, chlorite + quartz + calcite, and chlorite + andalusite assemblages are present. The andalusite alteration occurs solely in a metre-wide halo immediately surrounding the C- and H-zone orebodies and in a few of the trenches.

Within the area, 2 major east-trending faults bound a central graben. Displacement along the fault is approximately 200 m (*see* Figure 40.1). Numerous east-trending shear zones are also present throughout the area.

Canadian Jamieson Deposit

In late June and early July 2003, surface geological mapping, at scales of 1:5000 to 1:1000, was completed to better understand the volcanic stratigraphy, alteration mineralogy and structural deformation present in the immediate vicinity of the Canadian Jamieson orebodies (Figure 40.2). Between 1966 and 1971, these deposits produced 826 400 tonnes (816 000 tons) of massive sulphide ore averaging 2.4% Cu and 4.2% Zn (Binney and Barrie 1991; Barrie 2000). Geological mapping indicates that the Canadian Jamieson area contains an east-northeast-younging sequence of subaqueously deposited mafic and felsic lavas and volcaniclastic strata, chemical metasedimentary rocks (exhalites), and intermediate to mafic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458500
458600
458700
not mapped
not mapped
not mapped
MILL
TAILINGS
85
89
78
Bedding
88
Fault (inferred)
Pillow Tops
Foliation
88
Ore Zone (after Binney and Barrie 1991)
Outcrop Location
Olivine Diabase
Diabase
Rhyolite Tuff
Rhyolite Flow Breccia
Coherent Rhyolite Flow
Mafic Lapilli Tuff/ Tuff Breccia
Interbedded Rhyolite Tuff/ Exhalite
Massive Basalt
Pillow Basalt
Note: All UTM coordinates in NAD 83

Figure 40.2. Preliminary geological sketch map of the Canadian Jamieson deposit, Kamiskotia area.

intrusive rocks. From the base of the stratigraphic sequence, the geological section in the vicinity of the Canadian Jamieson deposit consists of

1. pillowed mafic to intermediate lava flows up to 140 m thick
2. laminated to thinly bedded, locally cross-bedded felsic tuffs up to 6.5 m thick
3. massive basalt lava flows up to 22 m thick
4. a second horizon of pillowed mafic to intermediate lava flows up to 60 m thick
5. interbedded felsic tuffs and sulphide mineral-rich chert horizons ranging from less than 10 up to 25 m thick
6. mafic lapilli tuffs and tuff breccia deposits up to 6 m thick
7. a spherulitic felsic (rhyolite) lava flow (up to 65 m thick) with associated basal (up to 13 m thick) and carapace (up to 25 m thick) flow breccias
8. very thinly bedded to medium-bedded felsic tuffs ranging from 10 to 20 m in thickness
9. a mafic lapilli tuff or tuff breccia horizon up to 40 m thick
10. a third horizon of pillowed mafic to intermediate lava flows that is up to 70 m thick
11. a felsic tuff horizon up to 80 m in thickness

Two distinctive intrusive units crosscut the volcanic and sedimentary stratigraphy in the vicinity of the Canadian Jamieson deposits. Fine- to medium- grained, north-northwest-trending Archean diabase dikes occur in the central and eastern parts of the study area. These dikes commonly contain polygonal tortoise-shell jointing, as well as columnar jointing, which is now horizontally inclined due to the steep dip of the strata. Such structures suggest these dikes are synvolcanic. Coarser grained olivine diabase dikes (Matachewan dikes) occur in the south-central part of the field area. Crosscutting relationships clearly indicate that the diabase dikes predate the olivine diabase dikes.

Based on vertical projections of the ore horizons (Binney and Barrie 1990; *see* Figure 40.2), massive sulphide mineralization at the Canadian Jamieson deposit appears to be associated with interbedded rhyolitic tuffs and chert-rich chemical metasedimentary rocks, rhyolitic lava flows and associated flow breccias, and mafic lapilli tuffs and tuff breccias. Based on surface exposures observed during field mapping, sulphide mineralization in the Canadian Jamieson area appears to have replaced the matrix of the volcaniclastic strata.

As previously noted by Binney and Barrie (1990), detailed mapping for this study indicates a lack of large-scale hydrothermal alteration associated with the Canadian Jamieson deposits. Felsic volcanic and volcaniclastic rocks contain up to 20% sericite locally, with only minor amounts of chlorite alteration. Mafic metavolcanic and volcaniclastic rocks contain abundant chlorite, with only minor amounts of sericite recognized in the field. Minor amounts of epidote veining have been recognized within the Archean diabase dikes near the Canadian Jamieson deposits.

Structural deformation in the northeast part of the property consists of north-northwest-trending shear zones up to 1 m wide in sericite-altered felsic lava flows and associated volcaniclastic rocks. Locally, northwest-trending boudin-like bodies of felsic tuff are located within diabase dikes. In the northeast part of the study area, structural deformation was largely confined to pre-existing phyllosilicate-rich hydrothermal alteration zones associated with massive sulphide mineralization in the volcanic and volcaniclastic strata.

DISCUSSION

Genex Deposit

This field work has changed the previous maps of the Genex area considerably. A large part of the mafic component initially mapped as intrusive (Legault 1985) consists of pillowed flows. The presence of mafic tuffs in the area has not been documented. The same is true for the felsic units; many were originally mapped as felsic intrusions, but are now identified as felsic tuff breccias and flows, with locally bedded volcaniclastic units. Thus, much of the Genex area is comprised of extrusive metavolcanic rocks, contrary to previous work in the area.

Detailed mapping (1:100 scale) of mafic pillowed flows immediately south of the C-zone orebody has documented significant variations in pillow size, morphology and flow direction that likely reflects down slope movement of the flow from a paleotopographic high. The north-bounding slope of the structure may be located along the Aconda Lake shore, marked by a small outcrop of amoeboid-shaped, brecciated pillows in a hyaloclastite matrix. Mapping of pillow flow morphology has also indicated that the crest of the paleotopographic high may be located at or near the C-zone orebody.

The contact between the mafic and felsic units throughout the map area is gradational. This lack of a sharp, straight-edged contact, along with the presence of numerous amoeboid mafic dikes in felsic material, may suggest that the onset of mafic volcanism occurred almost penecontemporaneously with the waning of felsic volcanism. Along the contacts between the 2 units, there is a pervasive metres-wide "mixed" zone in which both the felsic and the mafic units occur as blocks and apopheses into the other unit. This phenomenon has also been described by Hathway and Thurston (this volume) in the areas just to the west of the field area.

Petrography, geochemistry and diamond-drill core logging, planned for later this year, will further our interpretations.

Canadian Jamieson Deposit

Detailed mapping has recognized the volcanic facies that occur in the vicinity of the Canadian Jamieson deposits. In summary, the region comprises a bimodal stratigraphic sequence composed of Archean mafic to intermediate lava flows and volcaniclastic rocks, felsic lava flows and volcaniclastic rocks, chemical sedimentary rocks, and diabase dikes, as well as Proterozoic olivine diabase dikes. Pillowed mafic to intermediate lava flows, exhalite deposits and massive sulphide mineralization suggest deposition of the volcanic strata in a subaqueous environment. Tortoise-shell jointing and epidote-rich alteration veins within the Archean diabase dikes suggest thermal and chemical interaction with seawater. These jointed and altered intrusive rocks may represent synvolcanic feeder dikes to basalt lava flows that occur up-section of the Canadian Jamieson area. The distribution of these dikes may indicate the presence of synvolcanic structures that could be associated with hydrothermal up-flow zones and possible base-metal sulphide mineralization. Sericite- and chlorite-rich alteration mineral assemblages locally present in the Archean metavolcanic, metasedimentary and meta-intrusive rocks are consistent with mineral assemblages developed by subaqueous hydrothermal systems.

Due to a lack of subsurface data at the present time, it is difficult to determine with any certainty the spatial relationships of mineralization and stratigraphy in the Canadian Jamieson area. Based on field data collected during this study, it appears that massive sulphide mineralization occurs within interbedded rhyolite tuffs and chert-rich chemical metasedimentary rocks, rhyolite lava flows and associated flow breccias, and mafic lapilli tuffs and tuff breccias. The most eastern of the ore lenses, the "north ore zone" (Barrie 2000), is closely spatially related to strongly sheared felsic volcanic and volcaniclastic strata and Archean diabase dikes. This relationship suggests that some of the mineralization in the Canadian Jamieson area may have been concentrated by post-volcanic processes associated with structural deformation.

Petrographic studies, geochemical evaluations, structural analysis, and further mapping and diamond drill core logging will allow preliminary interpretations from this study to be further constrained.

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41. Discover Abitibi. Base Metal Subproject 3. Geology and Base Metal Mineralization in Ben Nevis, Katrine and Clifford Townships

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INTRODUCTION

The Blake River Group in Quebec has produced over 3 million tonnes of copper and zinc from volcanogenic massive sulphides (VMS) (Racicot 1990) in 17 past-producing deposits (Gibson and Watkinson 1990). Within this camp, the origin, localization and distribution of deposits are relatively well understood. Previous workers in the Blake River Group and the Noranda mining camp have illustrated that regional stratigraphy (Péloquin 1999), volcanic facies (Gibson 1989; Gibson and Watkinson 1990), alteration and mineralogical mapping (Gibson and Watkinson 1990; Hannington et al. 2003), isotopic research (Paradis et al. 1993; Cathles 1993), and subvolcanic intrusive complex studies (Galley 1993) were highly successful in outlining the distribution and localization of massive sulphide mineralization and, by association, are of use to the mineral industry in searching for new prospective stratigraphic horizons for massive sulphide mineralization.

In contrast, the Blake River Group in Ontario has received little modern geological, geochemical or isotopic study, although it lies just 50 km west of the Noranda mining camp. This Base Metal Subproject of the Discover Abitibi Initiative was conceived to provide stratigraphic and volcanologic facies and VMS-related alteration patterns related to VMS mineralization in the Blake River Group in Ontario.

The subproject has multiple goals:

1. to examine the stratigraphy hosting the VMS mineralization in Ben Nevis and Clifford Townships
2. to examine subvolcanic intrusions in the area and their relationship to volcanic rocks and associated mineralization (Clifford stock and associated intrusions)
3. to provide a reconnaissance section of the stratigraphy in Katrine Township
4. to acquire samples for geochronology and lithogeochemistry from both intrusive and extrusive facies of the assemblage

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FIELD DESCRIPTIONS AND RELATIONSHIPS

Ben Nevis Township

Stratigraphic sections were mapped at a scale of 1:20 000. Jensen's map was, for the most part, found to be very accurate (Jensen 1975b). The majority of the andesites are flows, massive or pillowed, and the majority of the rhyolites are volcaniclastic.

RHYOLITES

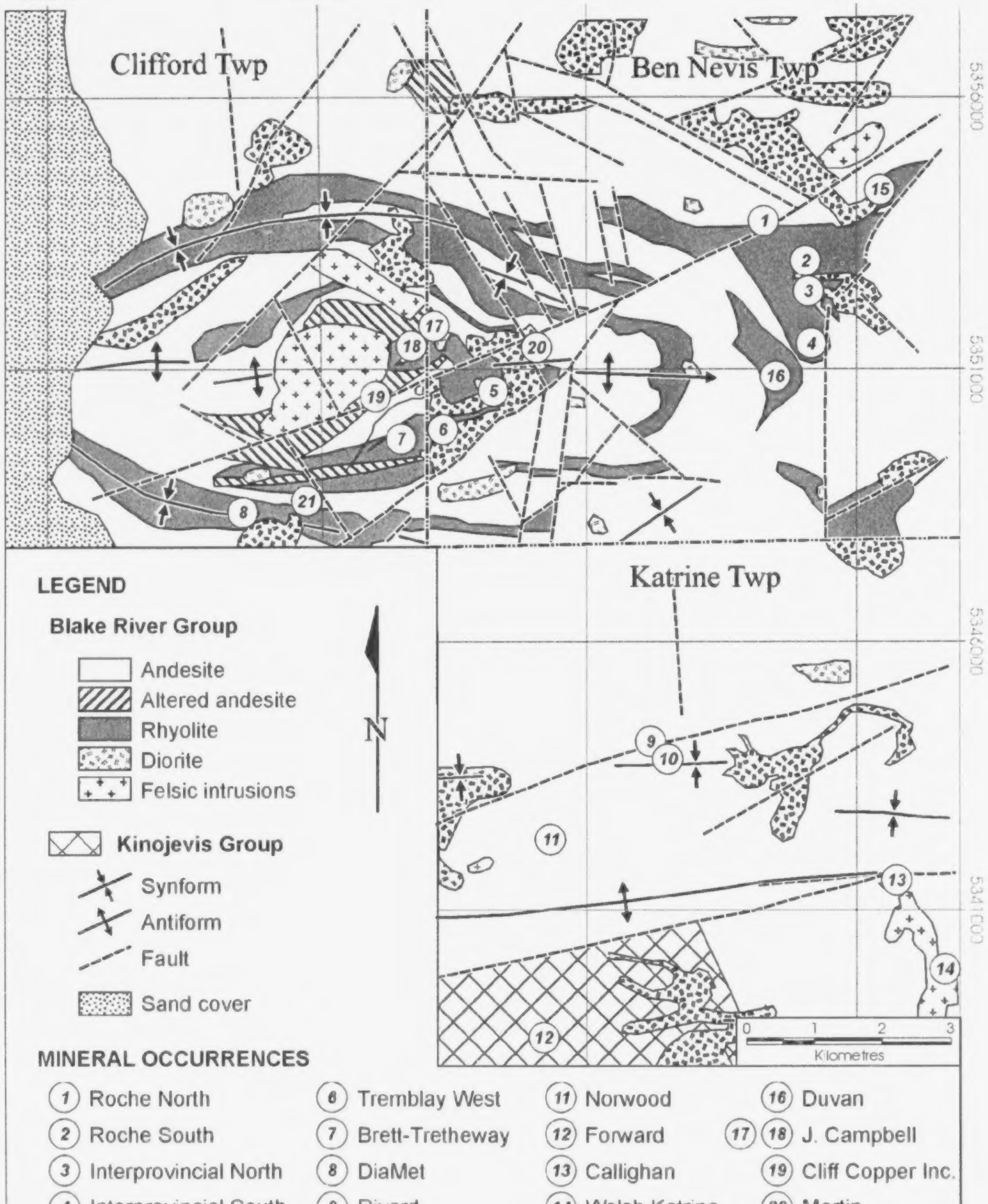
The rhyolite volcaniclastites are tuff breccias and lapilli tuffs, but some fine-grained massive and laminated tuffs occur. The rhyolite fragments are commonly highly quartz amygdaloidal; the tuffaceous matrix contains varied amounts of quartz and, less commonly, feldspar. Some of the rhyolites previously mapped as massive flows and breccia are lobe and breccia flow facies rhyolites (Furnes, Fridleifsson and Atkins 1980). Polygonally jointed massive rhyolites were recognized in the Interprovincial–Roche occurrences area (Figure 41.1; Canagau, Beaudry and Roche prospects in Jensen 1975a), and north of the northeast-trending fault cutting Clifford and Ben Nevis townships (*see* Figure 41.1); all were sampled for radiometric age determination. The flow and dome rhyolites are commonly silicified or sericitized. However, small (1 to 2 mm) quartz eyes are observed locally. One probable carapace, or dome collapse, breccia and associated massive rhyolite was observed in the nose of the Clifford antiform west of the Larder Station road (*see* Figure 41.1). In the area west of Interprovincial South (Duvan occurrence in Jensen 1975a), the rhyolites are dominantly dikes within variably silicified pillowed, commonly highly amygdaloidal, andesites (*see* Figure 41.1; Photo 41.1a). A geochronology sample was taken of one of these dikes.

The rhyolites in the Interprovincial and Roche area are generally highly altered and deformed. The alteration processes include intense silicification, sericitization, carbonatization or chloritization. Silicification is the most common and occurs in conjunction with the other alteration types. Sericitization and carbonatization are commonly spatially associated with deformation zones whereas the chloritized rocks are undeformed (Photo 41.1b).

ANDESITES

The andesites in Ben Nevis Township are commonly flows, exhibiting massive, pillowed and brecciated facies, and are generally aphyric to plagioclase microphyric. Many flows are amygdaloidal and some exhibit cooling fractures that are concentrically zoned around pillow margins. Amygdules are commonly 2 to 3 mm, but some highly amygdaloidal flows have quartz-filled or quartz-rimmed amygdules and vesicles up to 3 cm in diameter. In the northern fault block in Ben Nevis Township, the andesites are pillowed and massive, with an accumulation of thick massive flows. The presence of a rhyolite tuff bed within massive units of the sequence strongly supports an extrusive origin.

Chloritization, epidotization and silicification are the prevalent alteration types in the andesites. Chloritization commonly affects pillow rims, inter-pillow material and breccia matrix, where the hyaloclastite is preferentially altered. Epidote-silica alteration occurs as replacement of pillow rims and inter-pillow material, as veins and fracture-fillings and as irregular masses. Silicification occurs in massive flows and pillows as homogeneous pervasive alteration, and quartz in-filling of fractures and voids. In silicified breccias, the fragments are commonly rimmed with quartz or pervasively silicified, and the breccia matrix maybe be preferentially chloritized or exhibit net-textured quartz in-filling of fractures and voids.


585000
590000
595000
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5356000
5351000
5346000
5341000
Clifford Twp
Ben Nevis Twp
Katrine Twp
N
0 1 2 3
Kilometres
LEGEND
Blake River Group
Andesite
Altered andesite
Rhyolite
Diorite
Felsic intrusions
Kinojevis Group
Synform
Antiform
Fault
Sand cover
MINERAL OCCURRENCES
① Roche North
② Roche South
③ Interprovincial North
④ Interprovincial South
⑤ Tremblay A.
⑥ Tremblay West
⑦ Brett-Tretheway
⑧ DiaMet
⑨ Rivard
⑩ Lowe Katrine
⑪ Norwood
⑫ Forward
⑬ Callighan
⑭ Walsh Katrine
⑮ Beaudry
⑯ Duvan
⑰ ⑱ J. Campbell
⑲ Cliff Copper Inc.
⑳ Martin
㉑ Brazzoni

Figure 41.1. Simplified map of Clifford, Ben Nevis and Katrine townships (*after* Jensen 1975b; Hogg 1964b). The proposed Kinojevis-Blake River Group contact has been added to the map.

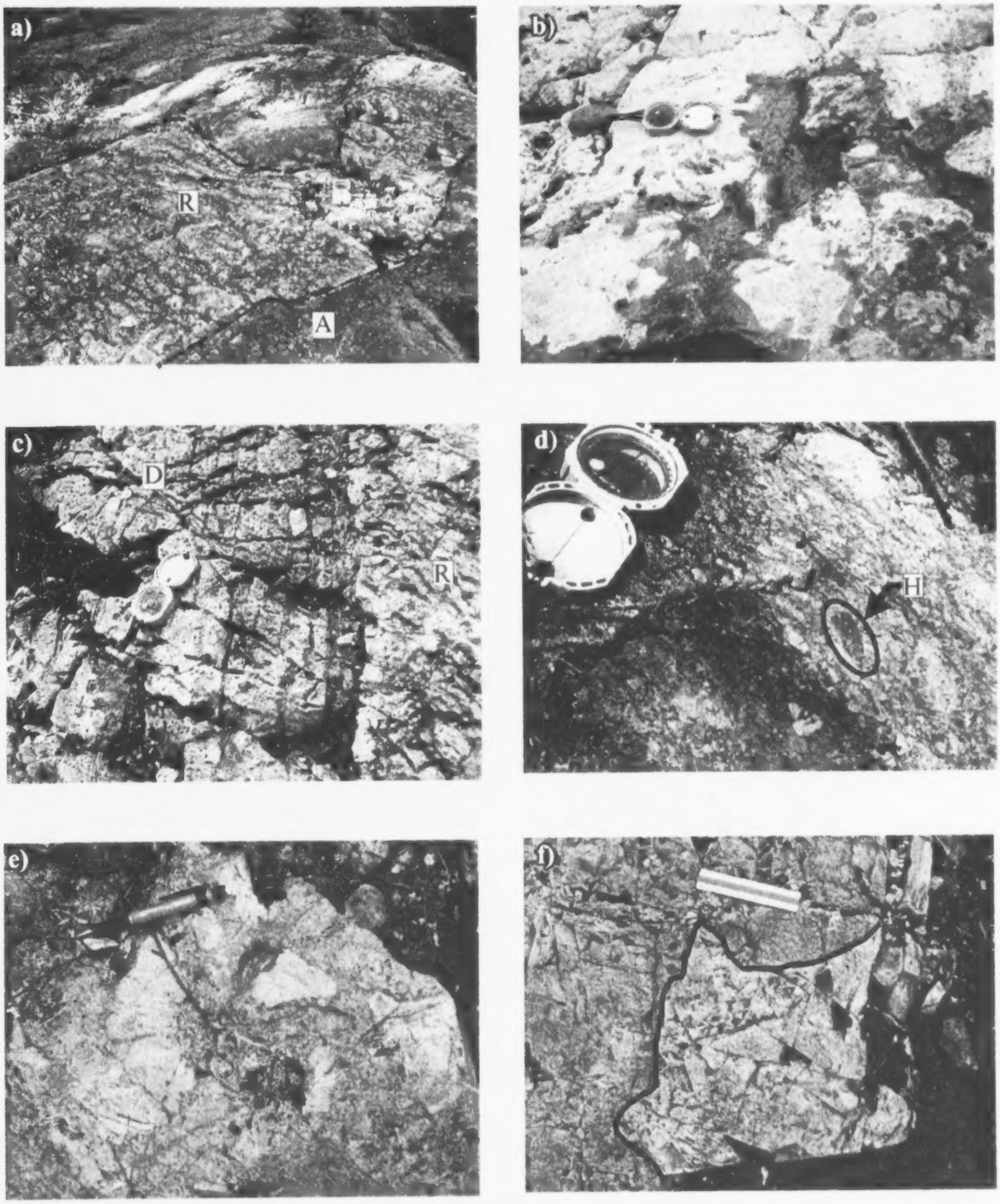

Photo 41.1. a) Rhyolite dike (R) cutting silicified amygdaloidal pillowed andesites (A) west of the Interprovincial South occurrence (Duvan prospect in Jensen 1975a). b) Chorite alteration (black) of massive rhyolite (white) at the Canagau Mine–Interprovincial North prospect. c) Multiple intrusive contacts of an fine-grained diorite dike (D) in a rhyolite breccia (R) at the Canagau Mine–Interprovincial North prospect. d) Jasperite fragment (H) in a polylithic tuff breccia in Katrine Township. e) Typical felsic tuff breccia with angular fragments of dacite to rhyolite within a siliceous tuffaceous matrix. f) Synvolcanic felsic dike (white, right-bottom corner) crosscutting andesite (grey) with an irregular, amoeboid margin suggesting emplacement into unsolidified andesite.

INTRUSIONS

The felsic and intermediate intrusions observed in Ben Nevis Township are similar to those in Clifford Township (see below). High-level felsic (rhyolite) dikes intrude the andesites, and one dike intrudes a dioritic intrusion. This implies that the diorites are also synvolcanic. High-level diorite (andesite) dikes are common in the Interprovincial–Canagau Mine area (*see* Figure 41.1), some showing multiple injections at their contacts (Photo 41.1c).

A small felsic to intermediate intrusion occurs along the axis of the Clifford antiform (*see* Figure 41.1). This intrusion is multi-phase and is apparently intercalated with felsic breccias. It is interpreted to be a subvolcanic sill complex and was sampled for geochronology.

Katrine Township

A stratigraphic section was mapped through Katrine Township at a scale of 1:20 000. Hogg's map for this area is somewhat oversimplified (Hogg 1964b). Andesites occur as massive, brecciated and pillowed facies; Hogg (1964a, 1964b) mapped no rhyolites in Katrine Township. In our traverses, no true rhyolites were recognized, but massive quartz-feldspar porphyry and felsic feldspar porphyry units were sampled to determine if they are related to the rhyolites or the syenitic intrusions. Also, a thick heterolithic tuff breccia contains rhyolite fragments, along with andesite and very rare jasper fragments (Photo 41.1d). One outcrop of highly sericitized tuff breccia was observed.

A polyphase syenitic intrusion in the southeast corner of the township (*see* Figure 41.1) is locally brecciated and contains xenolithic phases. Xenoliths are heterolithic, ranging from ultramafic (pyroxenite) to felsic (syenitic resembling other phases observed on outcrop).

No noticeable differences were observable between the andesite-basalt flows of the Kinojevis Group and those of the Blake River Group in the southern part of Katrine Township (*see* Figure 41.1). However, airborne total magnetic field and total magnetic field second derivative maps (Ontario Geological Survey 2003a, 2003b) indicate that the Misema Lake–Mist Lake fault may be a major boundary. Lithogeochemical samples were taken in this area to test this hypothesis.

Clifford Township

Southwest of the Clifford stock, the Blake River Group consists of an outward younging succession of basaltic-andesite, andesite, felsic volcaniclastic rocks and associated felsic and mafic to intermediate intrusions, which crosscut the volcanic rocks of the Blake River Group. The lowermost packages consist of pillowed to massive, basaltic andesite to andesite that is amygdaloidal and variably plagioclase porphyritic (where porphyritic plagioclase crystals are 2 to 3 mm long and relatively euhedral). Conformably overlying this amygdaloidal unit is non-amygdaloidal plagioclase-phyric andesite with fine euhedral plagioclase needles within a grey matrix. This andesite appears to be massive. Overlying this plagioclase-phyric unit is the first of 2 volcaniclastic units consisting of a matrix-supported tuff breccia (nomenclature from Fisher 1966). The tuff breccias are predominantly monolithic to weakly heterolithic with dominantly felsic angular fragments, from 1 to 30 cm, with most greater than 5 cm (Photo 41.1e), within a matrix of fine siliceous ash material. The breccia clasts are dacitic to rhyolitic with rare andesitic to basaltic andesitic clasts. Overlying the latter is a second unit of amygdaloidal and variably plagioclase porphyritic basaltic-andesite to andesite with small (<1 up to 2–3 mm) plagioclase feldspars. The uppermost stratigraphic unit consists of a second tuff breccia to lapilli tuff, very similar to the underlying tuff breccia, consisting of a matrix-supported breccia with angular clasts of predominantly dacite to rhyolite. There appears to be a southward younging of the tuff breccia into a lapilli tuff on a regional scale, suggesting normal grading outward from the Clifford stock.

Minor felsic metavolcanic flows do not occur at any defined stratigraphic horizon within the Blake River Group. At the Brett–Trethewey prospect (*see* Figure 41.1; Herrick prospect in Jensen 1975a), there is a feldspar porphyritic dacite dome with an associated carapace breccia. The dacite is relatively homogeneous with subhedral feldspar phenocrysts (up to 2 mm in size) within a grey to grey-green matrix. The carapace breccia consists predominantly of angular fragments of dacite, which are locally polygonally jointed and have concentric cooling rings. In this region, the void space between fragments within the carapace breccias are filled with quartz, pyrite and chalcopyrite. Previous workers have also reported molybdenite (Jensen 1975a). In the southern part of the Clifford Township, a second occurrence of felsic flows occur, and here they consist of white, aphyric rhyolitic rocks that are relatively massive in nature and do not have associated volcaniclastic rocks.

The Blake River Group is intruded by the Clifford stock, east-northeast-trending dikes interpreted as synvolcanic; Archean diabasic to gabbroic intrusive rocks; and gabbroic rocks of the Paleoproterozoic Matachewan dike swarm (*see* Figure 41.1). The Clifford stock is located in the core of the Blake River Group in Clifford Township and consists of a relatively equigranular diorite to granodiorite (commonly hornblende bearing and locally hornblende-biotite bearing). The intrusion does not appear to be polyphase and contains xenoliths of the surrounding wall rock in only a few localities. Southeast of the Clifford stock numerous east- to northeast-striking dike- to sill-like intrusions intrude the Blake River Group. These dikes are fine to medium grained, variably feldspar porphyritic, siliceous and dacitic to rhyolitic and locally pyrite bearing. These dikes crosscut stratigraphy, but, in most places, have irregular, amoeboid margins with their host rocks (Photo 41.1f). The dike–host rock relationships and accompanying hydrothermal alteration (see below) are relationships that have been observed in other massive sulphide camps and have been interpreted to represent vent-proxmity (Gibson, Morton and Hudak 1999; McPhie and Allen 1992; McPhie, Doyle and Allen 1993; Setterfield et al. 1995).

Mafic intrusive units cutting the Blake River Group stratigraphy are generally metamorphosed diabase to locally gabbro and are hard to distinguish from more mafic to intermediate volcanic rocks of the Blake River Group. These rocks may represent a subvolcanic feeder system to the basaltic-andesite to andesitic rocks of the Blake River Group. Also present are north-northwest-trending dikes of the 2.48 Ga Matachewan swarm. Unlike the Archean gabbro-diabasic rocks, these gabbroic dikes are coarse grained, have no recrystallization of primary igneous mineralogy and are highly magnetic.

Metamorphism in the Clifford area is relatively low grade, mostly prehnite-pumpellyite facies (Jensen 1975a; Hannington et al. 2003). In the area of the Clifford stock, a well-defined contact aureole surrounds the intrusion for 200 to 300 m. In the aureole, the basaltic-andesitic to andesite rocks exhibit a distinctive dark colouration and contain ubiquitous magnetite, lath-like needles of plagioclase (albite?), epidote patches and, in some cases, amphibole (actinolite?). In contrast, southwest of the stock, the rocks of the Blake River Group are crosscut by veinlets and patches of epidote-quartz (silica) with or without potassium feldspar and pyrite. In other localities, amygdules within lavas and interpillow material are replaced by epidote-quartz-pyrite-chlorite assemblages. It appears that this alteration is concentrated in an east-northeast-trending corridor following the trace of the synvolcanic dikes. Notably, this style of alteration is very similar to semi-conformable alteration observed in other VMS districts (e.g., Noranda: Galley 1993; Hannington et al. 2003).

RECOMMENDATIONS FOR EXPLORATION

The Blake River Group in Ben Nevis and Clifford townships is a bimodal andesite–rhyolite sequence. Although the rhyolites are dominantly volcaniclastic, the presence of polygonally jointed rhyolite domes, lobe and breccia rhyolite flows, and carapace or dome-collapse breccias indicate the proximity to volcanic vents. This proximity, so important in the formation of VMS deposits, is further confirmed by the recognition of high-level synvolcanic dikes. The presence of alteration corridors, such as that south of the Clifford Lake stock, and intense chloritization of the rhyolites in the area of the Canagau Mine, indicate that the rocks have interacted with hot hydrothermal fluids. In the Canagau Mine area, sulphide mineralization is observed in veins and stringers within, and often parallel to the contacts of, the synvolcanic dikes, both "rhyolitic" and "andesitic". This suggests that the synvolcanic dikes acted as conduits for the mineralizing hydrothermal fluid. For further exploration in this area, vent proximal facies and potential magma and fluid conduits should more closely examined.

The rocks in Katrine Township apparently lack the bimodal sequence observed in Ben Nevis and Clifford townships. However, the presence of heterolithic (rhyolite and andesite) tuff breccias indicates that rhyolitic volcanism occurred in the area. Reconnaissance mapping may reveal the source of these breccias.

ACKNOWLEDGMENTS

This project was supported by the Discover Abitibi Initiative. S.J. Piercey is also supported by a Natural Sciences and Engineering Research Council of Canada (NSERC) Discovery Grant. We thank Sara McIlraith and Zoran Madon of the Ontario Geological Survey for assistance and advice with GIS related issues. Discussions with colleagues, especially Phil Thurston, Harold Gibson, John Ayer, Doug Hunter and Ian Fraser are gratefully acknowledged. Wallbridge Mining Company Limited provided access to their properties and are gratefully acknowledged for this. Cheerful and capable field assistance was provided by Andrew Shannon and Chuck Lemieux.

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42. Project Unit 03-024. Comparison of Selective Leach Signatures Over Kimberlites, Carbonatites, False Anomalies and Blind Targets

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[1] Sedimentary Geoscience Section, Ontario Geological Survey

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INTRODUCTION

The Abitibi region of northeastern Ontario is home to many active mining companies who employ a large, highly trained workforce that is the mainstay of communities such as Timmins and Kirkland Lake. Recent mine closures have reaffirmed the transient nature of mining operations and the need for exploration in the region. The Discover Abitibi Initiative is a $12 million project, funded by federal, provincial and municipal governments and private sector companies, that was set up to satisfy that need. Two important goals of the project are exploration in the Abitibi greenstone belt and the development of new and affordable exploration methods, which can be employed by both individual prospectors and large companies (Discover Abitibi Initiative web site www.discoverabitibi.com accessed September, 2003).

Airborne magnetic survey anomalies may indicate the position of kimberlites or other economically important deposits. In areas of thick glacially transported overburden, such as the Abitibi region, it is difficult to determine the nature of these anomalies without time-consuming heavy mineral indicator till sampling or expensive drilling programs. In recent years, the Ontario Geological Survey and its partners have focussed on developing new methods for prospecting in areas of thick drift.

One of these new methods is the use of a selective leach digestion of surface samples to detect high concentrations of key elements, such as calcium, strontium, copper, cobalt, nickel and barium, over deeply buried mineral deposits (Hamilton et al. 2002a). Mobile metals move upward through thick overburden from the mineral deposit and concentrate in the upper part of the soil profile. Weak selective leaches can be used to dissolve the mobile ions that loosely adhere to soil grains leaving the grains themselves intact. This means that chemical signatures related to the upward movement of mobile metals from local sources are detected. A total digestion would yield a chemical signature related to the distant source zone of the glacially transported material.

Previous selective leach studies have focussed on developing sampling protocols, evaluating the effectiveness of different extraction techniques and determining which elements are most useful for defining the limits of mineralization. The purpose of this study is to define and compare selective leach signatures over known kimberlites, carbonatites, proven false anomalies and blind targets. This will help prospectors to evaluate and differentiate magnetic targets quickly and cheaply. A wide variety of sediments will be analyzed including peat, glaciofluvial sand, glaciolacustrine silt and clay, till and postglacial alluvium.

This study falls within the Discover Abitibi Initiative mandate to develop new exploration methods and, as such, is being jointly funded by Discover Abitibi and the Ontario Geological Survey.

Summary of Field Work and Other Activities 2003,
Ontario Geological Survey, Open File Report 6120, p.42-1 to 42-10.

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LOCATION AND ACCESS

Individual study sites are located in 3 regions of northern Ontario (Figures 42.1 to 42.3). Sixteen kimberlites are located in the Kirkland Lake region, longitudes 79°40′W to 80°15′W and latitudes 48°05′N to 48°30′N, which is found within 1:50 000 scale NTS map sheets 32 D/4, 32 D/5, 42 A/1 and 42 A/8 (*see* Figure 42.1). Twelve kimberlites and 2 false anomalies are located in the Cobalt–New Liskeard region, longitudes 79°35′W to 80°00′W and latitudes 47°20′N to 47°35′N, which is found within 1:50 000 scale NTS map sheets 31 M/5 and 31 M/12 (*see* Figure 42.2). Three carbonatite complexes and the blind target are located in the Wawa–Chapleau region, longitudes 83°05′W to 84°45′W and latitudes 46°55′N to 48°05′N (*see* Figure 42.3). The study sites are covered by 1:50 000 scale NTS map sheets 41 J/14, 41 N/15, 41 O/11 and 41 O/14.

Road access is variable throughout each region. Several kimberlites are within 500 m of highways or secondary roads and can be accessed by truck. The remaining sites are accessed by all-terrain vehicle (ATV) along logging and drill roads that are in varying stages of forest regeneration and/or by foot through dense bush and swamps.

BEDROCK GEOLOGY

Kirkland Lake Region

The Kirkland Lake region is dominated by Superior Province Neo- to Mesoarchean mafic to intermediate metavolcanic supracrustal rocks including basaltic and andesitic flows, tuffs, breccias, chert, iron formation, minor metasedimentary and intrusive rocks and related migmatites (Ontario Geological Survey 1991). Minor rock types include Neo- to Mesoarchean mafic to ultramafic metavolcanic and felsic to intermediate metavolcanic supracrustal rocks, Neoarchean coarse clastic metasedimentary supracrustal rocks, Neo- to Mesoarchean mafic and ultramafic and diorite + monzonite + granodiorite intrusive rocks and Paleoproterozoic Cobalt Group (Huronian Supergroup) sedimentary rocks of the Southern Province. Proterozoic diabase dikes and numerous Late Jurassic kimberlite pipes and dikes have intruded these host rocks. Kimberlite geology is site specific and includes examples of both diatreme and hypabyssal facies (Averill and McClenaghan 1994; Kjarsgaard et al. 2003; McClenaghan et al. 1996; McClenaghan et al. 1998; McClenaghan and Kjarsgaard, in press; Sage 1996, 2000).

Cobalt–New Liskeard Region

The Cobalt–New Liskeard region is dominated by Southern Province Paleoproterozoic sedimentary Cobalt Group rocks, which include conglomerate, wacke, arkose, quartz arenite and argillite and diabase dikes and sills (Ontario Geological Survey 1991). Minor rock types include Neo- to Mesoarchean mafic to intermediate metavolcanic supracrustal rocks and Upper Ordovician, Middle Silurian and Late Silurian limestone, dolostone, siltstone, shale, arkose and sandstone. As with the Kirkland Lake region, Proterozoic diabase dikes and Late Jurassic kimberlite pipes and dikes have intruded these host rocks.

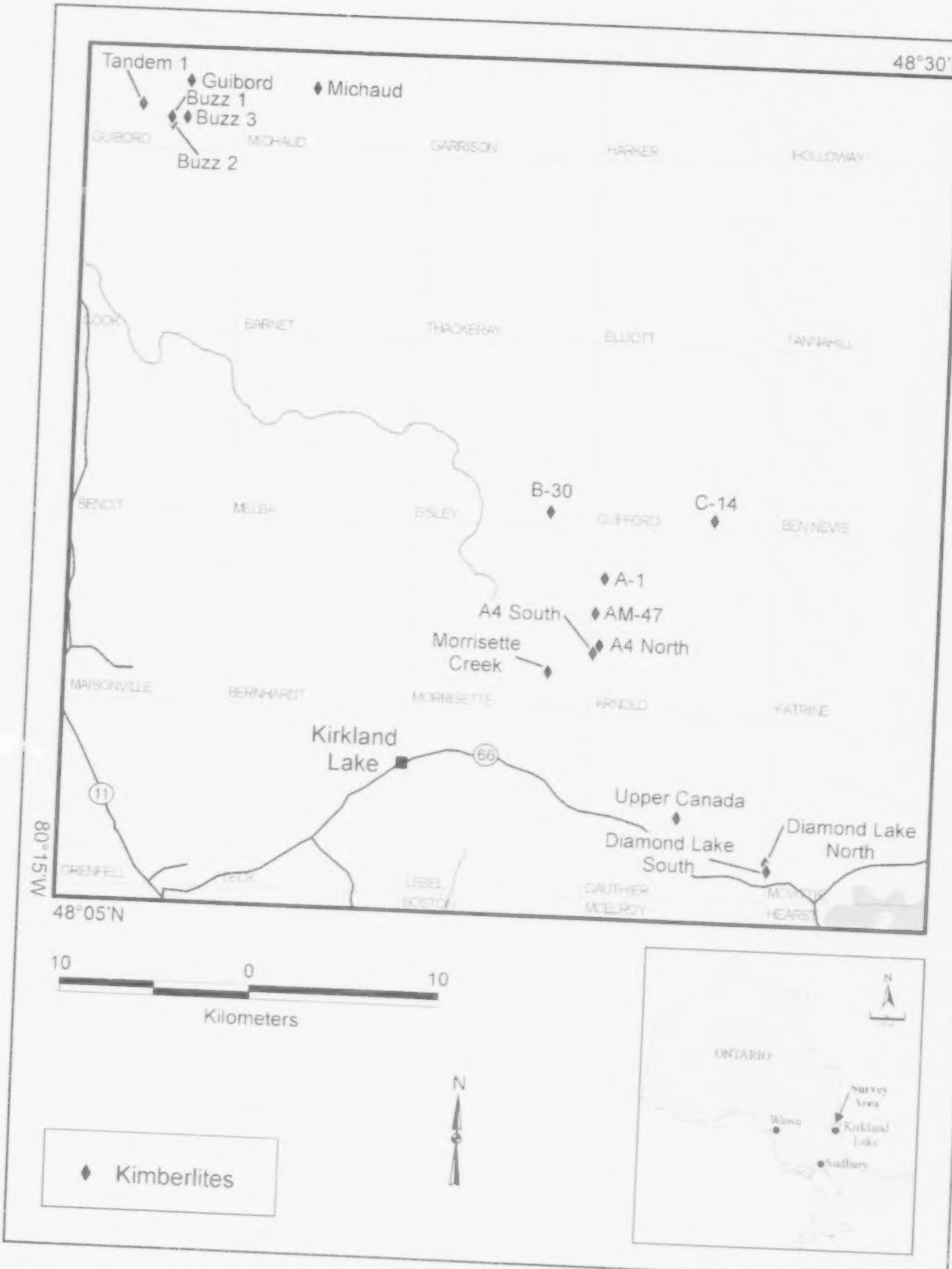
Tandem 1
Guibord
Buzz 1
Buzz 3
Buzz 2
Michaud
48°30'N
79°40'W
GUIBORD
MICHAUD
GARRISON
HARKER
HOLLOWAY
BARNET
THACKERAY
ELLIOTT
TANNAHILL
B-30
C-14
BENOIT
MELBA
BISLEY
CLIFFORD
BEN NEVIS
A-1
A4 South
AM-47
A4 North
Morrisette Creek
MAISONVILLE
BERNHARDT
MORRISETTE
ARNOLD
KATRINE
Kirkland Lake
66
11
Upper Canada
Diamond Lake North
Diamond Lake South
80°15'W
GRENFELL
TECK
LEBEL
BOSTON
GAUTHIER
MCELROY
HEARST
48°05'N
10
0
10
Kilometers
N
Kimberlites
ONTARIO
Survey Area
Wawa
Kirkland Lake
Sudbury

Figure 42.1. Location of kimberlites in the Kirkland Lake study region.

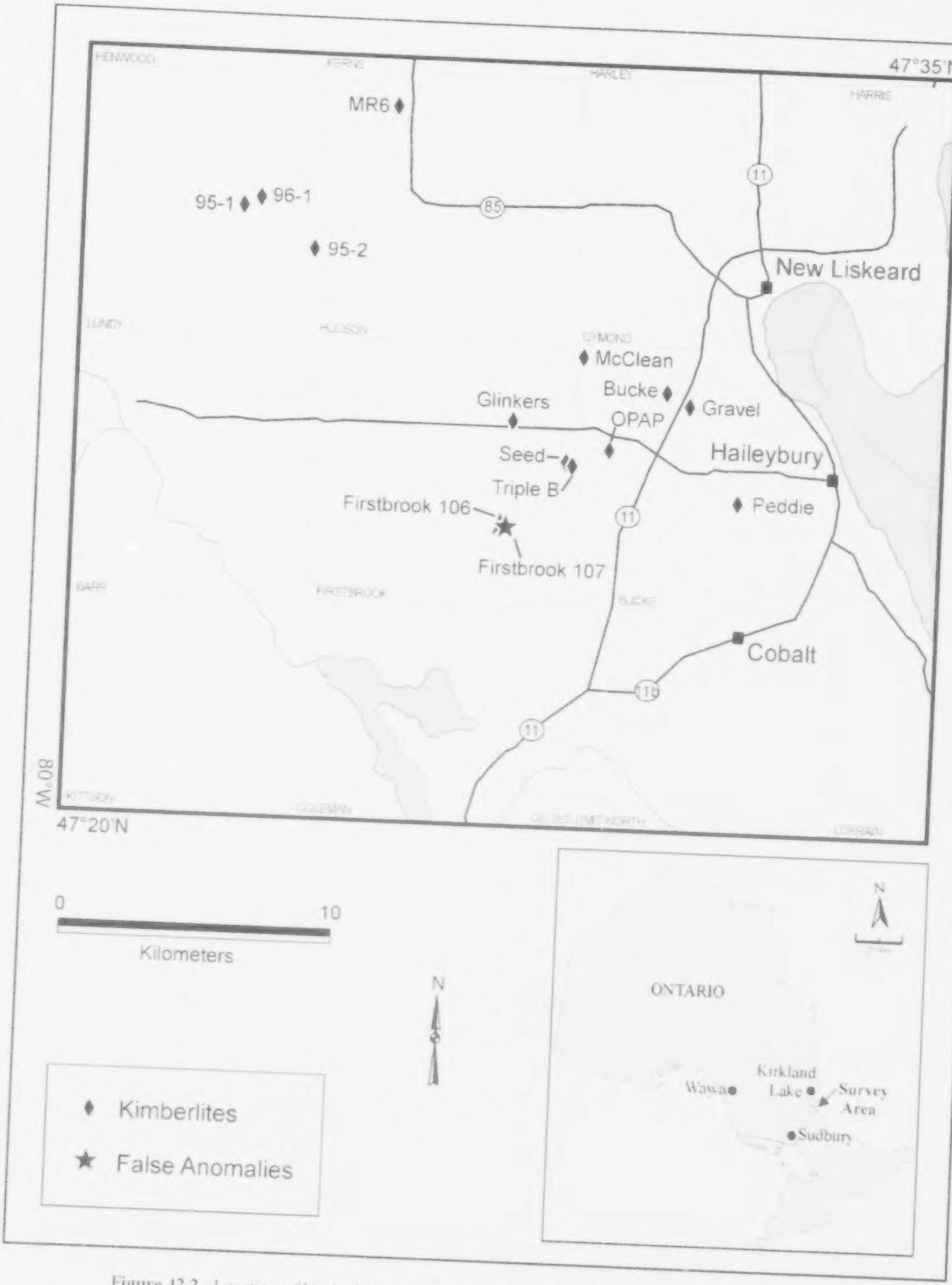
HENWOOD
KERNS
HARLEY
HARRIS
47°35'N
79°35'W
MR6
95-1
96-1
95-2
11
85
New Liskeard
LUNDY
HUDSON
DYMOND
McClean
Bucke
Gravel
Glinkers
OPAP
Haileybury
Seed
Triple B
Firstbrook 106
Peddie
Firstbrook 107
BARR
FIRSTBROOK
BUCKE
Cobalt
11B
80°W
KITTSON
COLEMAN
GILLIES LIMIT NORTH
LORRAIN
47°20'N
0
10
Kilometers
N
Kimberlites
False Anomalies
ONTARIO
Wawa
Kirkland Lake
Survey Area
Sudbury

Figure 42.2. Location of kimberlites and false anomalies in the New Liskeard–Cobalt study region.

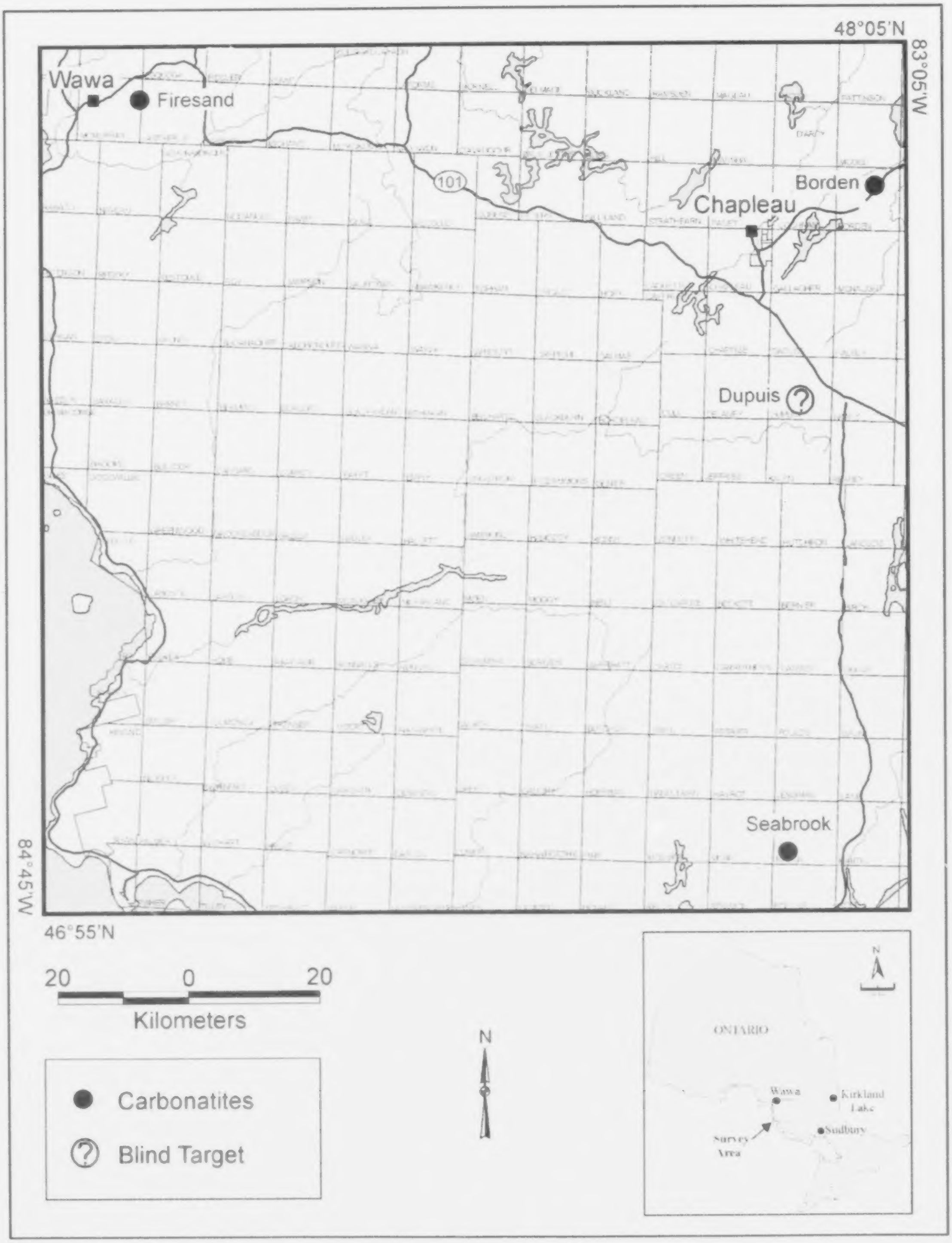
48°05'N
83°05'W
Wawa
Firesand
101
Borden
Chapleau
Dupuis
Seabrook
84°45'W
46°55'N
20
0
20
Kilometers
Carbonatites
Blind Target
N
ONTARIO
Wawa
Kirkland Lake
Sudbury
Survey Area

Figure 42.3. Location of carbonatites and the blind target in the Wawa–Chapleau study region.

Wawa–Chapleau Region

The Wawa–Chapleau region is dominated by Superior Province Neo- to Mesoarchean intrusive rocks composed of foliated to gneissic tonalite to granodiorite with minor supracrustal inclusions (Ontario Geological Survey 1991). Other important rock types include Neo- to Mesoarchean intrusive massive to foliated granodiorite to granite and Neo- to Mesoarchean supracrustal mafic to intermediate metavolcanic rocks such as basaltic and andesitic flows, tuffs and breccias, chert, iron formation, minor metasedimentary and intrusive rocks and related migmatites. Minor rock types include Neo- to Mesoarchean felsic to intermediate metavolcanic, metasedimentary and migmatized supracrustal rocks and Neo- to Mesoarchean mafic and ultramafic rocks, foliated to massive tonalite to granodiorite and a diorite + monzonite + granodiorite suite. These host rocks have been crosscut by Proterozoic diabase dikes and intruded by Meso- and Paleoproterozoic carbonatite-alkalic intrusive complexes (carbonatites).

The carbonatites are characterized by a variety of dike, core and rim rocks (Sage 1987, 1988a, 1988b). The dike rocks commonly include sövite, silicocarbonatite, lamprophyre, ferruginous carbonate, mafic alkaline rocks and biotite-calcite rocks. The core and rims of the complexes include combinations of ferruginous dolomite, sövite, silicocarbonate, biotite, ijolite, malignite and fenitized granite and granite breccia. This study is targeting the sövite core and rim rocks.

SURFICIAL GEOLOGY

Most of the sediments and landforms seen across Ontario today are the result of the Late Wisconsinan glaciation. The Labrador-centred ice sheet advanced to its maximum position in the northern United States by 18 000 years BP (Dyke and Prest 1987). Parts of the ice sheet were dominated by erosive processes whereas other regions were characterized by deposition. By 14 000 years BP the ice sheet was in retreat, punctuated by short-lived periods of surging and readvance, and the ice margin had receded northward into the study areas by 10 000 years BP. Subglacial till was deposited at the glaciers' base; englacial and supraglacial meltout till overlies the lodgement material. Meltwater carried vast quantities of sediment to the glacier margin both within and beneath the ice. Some of this sediment was deposited as sand and gravel eskers and outwash complexes on route to the glacier margin. Blocks of ice were occasionally buried in the till and outwash forming kettles when they melted. In some areas, huge glacial lakes followed the retreating ice margin, forming depositional basins for fine-grained sediments.

Kirkland Lake and Cobalt–New Liskeard Regions

Glacial sediments in the Kirkland Lake region generally range from less than 1 to 30 m in thickness. Weathered kimberlites are softer than the surrounding host rock and, therefore, are more deeply eroded resulting in overburden thicknesses up to 60 m over some pipes (Kjarsgaard et al. 2003). There are areas of exposed bedrock with discontinuous drift and postglacial organic deposits between local topographic highs (Barnett, Henry and Babuin 1991). There are also patches of continuous till with minor organic deposits. The surficial till is olive grey and has a silty sand matrix with 5 to 20% clasts (Kjarsgaard et al. 2003). Southward-trending esker and outwash complexes are found throughout the region. Silt and clay from glacial lake Barlow–Ojibway blankets topographic lows throughout the Kirkland Lake region and the northeast of the Cobalt–New Liskeard region. Modern alluvium is found along the floodplains of rivers and streams.

Wawa–Chapleau Region

Most of the Wawa–Chapleau region is characterized by exposed bedrock highs with thin discontinuous drift and postglacial organic deposits in the intervening lows (Barnett, Henry and Babuin 1991). There are small areas of continuous till cover throughout the northern and eastern portions of the region. Both the discontinuous and continuous till have a sand to silty sand matrix with a high clast content. Small pockets of outwash are found throughout the region. A large, thick esker and outwash complex covers 22 townships in the northeast. Modern alluvium is found in narrow bands along the floodplains of rivers and streams.

METHODS

Site Selection

The traditional approach to sampling for geochemical responses has been to sample at regular intervals along a transect (Hamilton et al. 2002a). This approach has shown that geochemical signals form a single peak that is uniformly high over mineralization (i.e., volcanogenic massive sulphide (VMS), kimberlite). In the current study, a more streamlined sampling program has been adopted. Sample sites are selected from near the centre of the target and from background areas that are outside the target (Figure 42.4). It is anticipated that this sampling strategy will detect the peak over the mineralization while minimizing ambiguous results near the edges. It should also be faster and more cost effective, which is important to prospectors. The site selection protocol used in this study is as follows:

1. Use global positioning system (GPS) to locate the approximate centre of the target.
2. Select a location for sampling. There must be room to collect a cluster of samples from 3 sites 10 to 15 m apart with the same site conditions and sampling medium. Disturbed sites should be avoided.

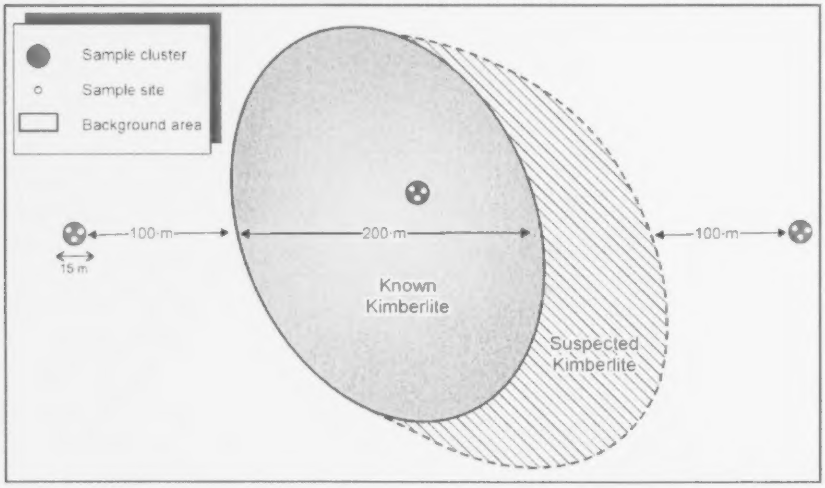

Figure 42.4. Idealized location of sample sites in sample clusters on kimberlite and in background area. Background samples are taken at least 100 m away from well-defined kimberlite boundaries. This distance is increased if the kimberlite is poorly defined or when working from airborne magnetic maps.

3. Collect a cluster of samples from 3 sites at least 100 m off the target (background samples). It may be necessary to sample further into the background if the boundaries are ambiguous or unknown. Whenever possible, the same medium should be sampled over the kimberlite and in the background areas.
4. Collect a second cluster of background samples from the opposite side of the target.

Sampling Protocol

Previous selective leach sampling programs have shown that careful sampling at a consistent depth is critical for obtaining reliable results (Cameron et al. in press; Hamilton et al. 2002a, 2002b). Furthermore, the sampling must target a zone where metals are known to accrete, such as the Ae horizon in well-drained mineral soils, so different protocols are followed in peat and mineral soils. Although not as critical as depth, sampling a consistent medium is also important. Two selective leach samples are taken at each sample site for a total of 18 samples per target. The sampling protocols used in this study are outlined below.

ALL SITES

1. Record the location of the sample cluster using a GPS rover file and waypoint.
2. Core to a depth of at least 40 cm to establish whether the peat or mineral soil protocol should be used. The peat protocol is used where there is more than 30 cm of peat. The mineral soil protocol is used where there is less than 20 cm of peat. A mixed protocol is used where there is 20 to 30 cm of peat.
3. Photograph the core ensuring that a tape measure and numbered sample bag are visible. Photograph the site. Record site and sample information on a handheld computer (e.g., PalmPilot™).

PEAT

1. Measure and remove sphagnum mat. The contact between the sphagnum mat and underlying peat is considered to be the ground surface for sampling purposes.
2. Core to a depth of 20 cm. The upper half of the core (0 to 10 cm below surface) is discarded (away from the cleared sampling area) and the lower half of the core (10 to 20 cm below surface) is placed in a pre-labelled 15 by 30 cm plastic sample bag.
3. Repeat step 2 until enough material has been gathered. This will vary depending on the decomposition of the peat: half a bag is sufficient for well-decomposed peat, whereas three-quarters of a bag is required for poorly decomposed peat.
4. Reusing the original holes, core to a depth of 40 cm. This time the upper half of the core (20 to 30 cm below surface) is retained and the lower half of the core (30 to 40 cm below surface) is discarded. Repeat until enough material has been gathered.
5. Obtain small representative samples for pH analysis and place in pre-labelled 10 by 20 cm plastic sample bags. Squeeze the air and excess moisture from the bags prior to sealing. The pH samples should be frozen as soon as possible.

MINERAL SOIL

1. Measure and remove sphagnum or root mat.
2. Measure thickness of the soil humus. Sample the humus ensuring that clastic contamination is kept to a minimum. The volume of material required depends on decomposition as outlined in step 3 of the peat protocol.
3. Once most of the humus has been removed, core to a depth of 20 cm. Sample the upper 10 cm of organic-free mineral soil and place in a pre-labelled plastic sample bag. Repeat until one-quarter of a bag has been gathered.
4. Obtain pH samples as outlined in step 5 of the peat protocol.

ANALYSIS

Sample preparation and analysis is currently underway as field work has been completed. The samples will be air dried, split and analyzed by inductively coupled plasma mass spectrometry (ICP–MS) after digestion by a selective leach. The samples will be submitted as a single batch to reduce the chance of sample mix-up. The laboratory results will be plotted to aid in the interpretation of the geochemical signal over the various targets. It is anticipated that the kimberlite will have a different chemical response than the carbonatites and proven false anomalies. This will mean that selective leach techniques can be used for exploration purposes to identify likely kimberlites, which can then be cored.

PROJECT STATUS

Nineteen kimberlites, 3 carbonatites, 2 false anomalies and 1 blind target were selected for sampling based on the size of the target, reliability of precise location information and sufficient depth to bedrock. Of these, 11 kimberlites, the 3 carbonatites, both false anomalies and the blind target were sampled. The remaining 8 kimberlites were not sampled due to lack of suitable sampling medium, agricultural disturbances or lack of access.

The results of this study will be released in the spring of 2004.

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Lake Nipigon Region Geoscience Initiative

43. Lake Nipigon Region Geoscience Initiative. A Progress Report

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INTRODUCTION

The Ontario Prospectors' Association (OPA) is undertaking, with financial support from the Northern Ontario Heritage Fund Corporation, a two-year program of geoscience studies.

The Lake Nipigon Region Geoscience Initiative (LNRGI) is a science-based geological data acquisition and compilation study that will conduct research and collect new geoscientific observations that will explain the geological history of the Lake Nipigon region. It will also identify high mineral potential targets in the region that will attract mineral exploration in areas other than parks and conservation reserves.

GEOSCIENCE IMPORTANCE OF THE REGION

The Lake Nipigon region is of interest to the Ontario, Canadian, and international geological community because the rocks appear to preserve evidence for the rifting of the Earth's surface approximately 1 billion years ago. The Nipigon area is presently interpreted to be the failed third arm of a major Proterozoic Rift that transects midcontinent North America beneath Lake Superior, the Keweenawan Subprovince. Documented evidence of crustal rifting processes preserved in the Lake Nipigon region will enhance the understanding of the geological history of this immediate area and the geological history of rocks preserved south of Thunder Bay and into the United States. Data collected from the north and west shores of Lake Superior will be used by the Ontario Geological Survey (OGS) as part of their five-year core business commitment to the area and as part of a joint OGS–United States Geological Survey compilation project to understand the geological history of the entire Midcontinent Rift system.

Elsewhere in the world, similar Earth processes have concentrated metals in the crust, including nickel-copper, platinum group elements (PGE), copper-gold, gold and rare metals, to levels where they form economically viable ore deposits. Important insights gained by studying this region will be applied to more effectively explore for mineral resources in this region and elsewhere in Ontario.

RATIONALE FOR THE PROGRAM

Several specific geoscience questions will be addressed during this study. Part of our existing knowledge gap is due to the fact that much of the study area has not been mapped or sampled in detail. For example, undocumented areas of Archean rocks have been reported from the study area, but, until the

Summary of Field Work and Other Activities 2003,
Ontario Geological Survey, Open File Report 6120, p.43-1 to 43-6.

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character and distribution of these rocks are known, they have unknown mineral potential. Also, the Sibley Group of sedimentary rocks and the English Bay felsic intrusion contain the oldest elements of the Keweenawan rift system. These studies will aid our understanding of the relationship of these elements and their implications for resource potential. In addition, Operation Treasure Hunt lake sediment geochemistry surveys identified metal anomalies in the area that may be indicative of unknown mineral occurrences. Both the surficial geochemical and bedrock mapping studies will help to determine the cause of these anomalies.

Although the region has undergone recent exploration for Ni-Cu-PGE mineralization associated with mafic intrusions (1100 Ma), it is not known whether mineralization type varies between intrusion forms (e.g., cone sheets versus sills or lopoliths). The distribution of felsic intrusions and related metavolcanic rocks (~1530 Ma) in the English Bay area is not well known, nor is the potential for iron-oxide-gold-copper mineralization in association with these felsic intrusions. The Black Sturgeon fault has been suggested as an important controlling factor with respect to distribution of mafic intrusions, and possibly mineralization. Consequently, determining its precise location, as well as comparing stratigraphy across the fault, will be important in determining the metallogenic significance of this structure. Geochemical studies of the mafic intrusions will help in establishing the internal stratigraphy of these units, as well as aiding in determining the processes responsible for mineralization.

The acquisition of high-resolution geophysical data for the Lake Nipigon Region as part of this project will not only play a role in defining potential exploration targets, but, when integrated with the bedrock mapping results, will help to better define geological contacts and regional geological structures.

GOAL OF THE LAKE NIPIGON REGION GEOSCIENCE INITIATIVE

The Lake Nipigon Region Geoscience Initiative projects will enhance the scientific understanding of the area and facilitate mineral exploration in the region by

1. collecting geoscience observations that describe the physical characteristics of the local geology
2. providing new detailed geological maps of the western Nipigon Embayment with integrated geophysical data and geochronological data
3. providing interpretations of the geoscience data to explain the local geological history
4. contributing to a geological synthesis of the region
5. advancing the scientific understanding of the region which will provide concepts and methodologies that the mineral exploration community can apply in the Lake Nipigon Region and elsewhere in Ontario
6. provide a framework for informed future land use decisions
7. help attract interest from international and domestic investors to encourage new mineral exploration investment in high mineral potential areas in the region and adjacent areas

Local communities have been invited to support and participate in the present geoscience activities. If a new mine is discovered in the region, all communities will benefit from the resulting jobs and other economic benefits. As well, the information gathered from the LNRGI will add to knowledge of the geology of the various protected areas in the Lake Nipigon region. This information will increase knowledge of the natural processes that have occurred within the protected areas and will provide a significant resource for future interpretive programs.

Geoscience data will be gathered in a variety of ways using low-flying aircraft, helicopter, all-terrain vehicles (ATV), snow machine or boat. Geoscientists on the ground will be taking measurements with a variety of different instruments, or mapping out and measuring various rock occurrences.

FUNDING

The Lake Nipigon Region Geoscience Initiative received $3.5 million funding from the Northern Ontario Heritage Fund Corporation, which has been matched by in-kind support from local partners.

GEOSCIENCE PROJECTS

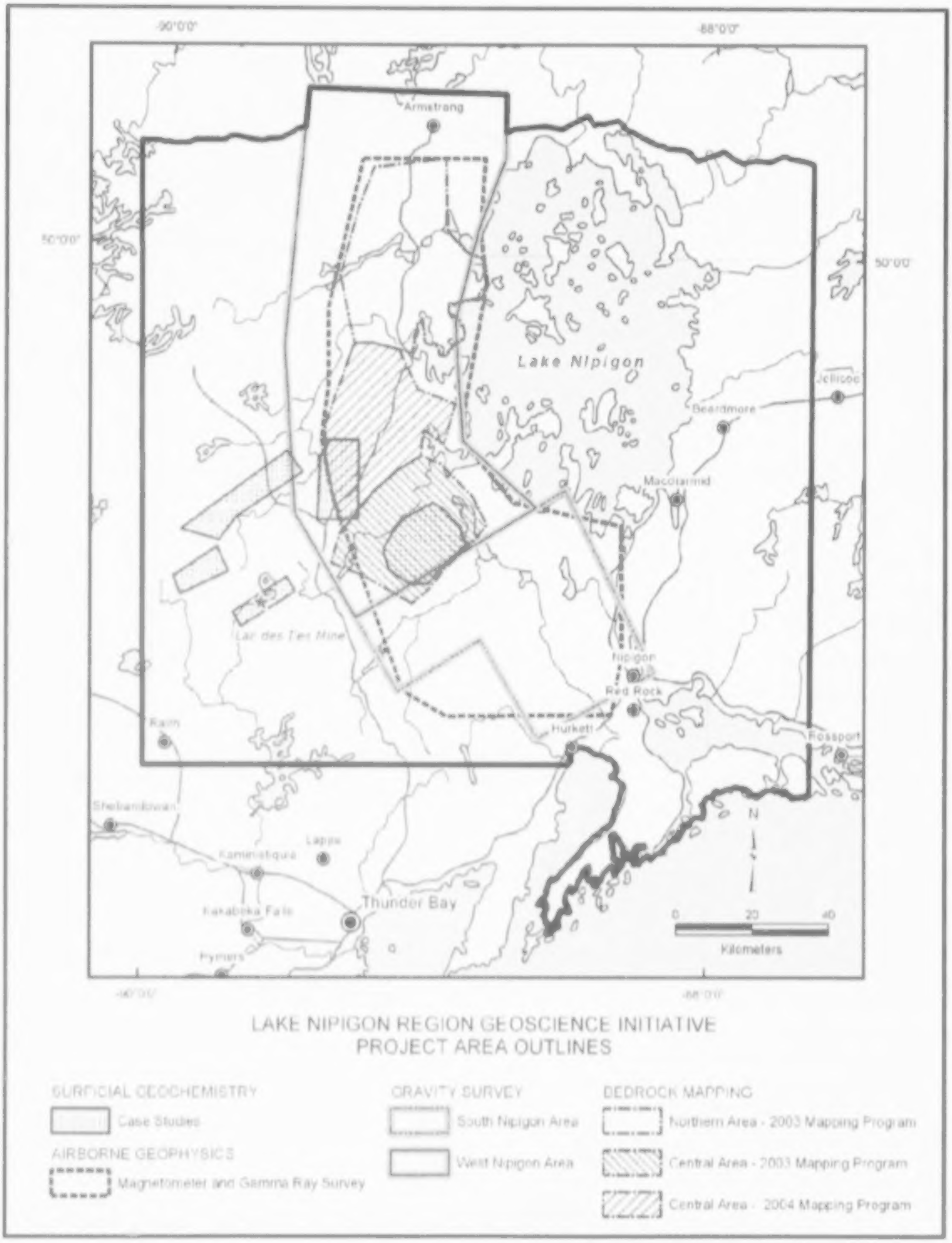
As of September 22, 2003, the following projects are underway or planned for the Lake Nipigon Region. Figure 43.1 shows the area of the LNRGI as well as the boundaries of the geoscience projects described below.

Geological Mapping

Bedrock mapping, at a scale of 1:50 000, will occur in 2 blocks within the western Nipigon area (Hart and MacDonald, this volume). The projects have been designed to gather geological data over key areas in the western part of the Nipigon Embayment in order to address several geoscience problems. The geological mapping is being completed in parks and protected areas with in the region under permit from the Ministry of Natural Resources (MNR) and Parks Ontario. Light "footprint" bedrock mapping will be carried out without significant disturbance to the natural environment. Navigation is being done using global positioning systems (GPS). Bedrock outcrops will be located, sampled and described, and key stratigraphic units will be sampled for geochronology. Rock samples are also being collected for determination of rock properties, including density and magnetic susceptibility, for integration with the geophysical surveys. All data collected will be made public, and specific data and maps of the park areas could be reproduced for park use. The results of the geological mapping will be incorporated with the other geoscience data to generate an integrated interpretation of the geological history. These data and interpretations contribute to the regional geological interpretation that will be carried out by the OGS after the entire region is mapped. The field mapping of the north block will be completed in the fall of 2003. The adjoining central block to the south will be mapped in 2004.

Aeromagnetic and Gamma Ray Spectrometry

This survey was completed on August 28, 2003, and was conducted over a large area west of Lake Nipigon. The fly-over of the Gull Bay First Nation reserve was negotiated with the band council. The MNR permit also acknowledged the fly-over of the parks and protected areas in the region. Reports and maps will be provided to both the Gull Bay First Nation and Parks Ontario, at the time of the public release of the results of the airborne surveys, scheduled for early 2004.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Red Rock
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Rossport
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Shebandowan
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Kaministiquia
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LAKE NIPIGON REGION GEOSCIENCE INITIATIVE
PROJECT AREA OUTLINES
SURFICIAL GEOCHEMISTRY
Case Studies
AIRBORNE GEOPHYSICS
Magnetometer and Gamma Ray Survey
GRAVITY SURVEY
South Nipigon Area
West Nipigon Area
BEDROCK MAPPING
Northern Area - 2003 Mapping Program
Central Area - 2003 Mapping Program
Central Area - 2004 Mapping Program

Figure 43.1. Area of interest encompassed by the Lake Nipigon Region Geoscience Initiative, as well as the location of the geoscience projects active in 2003. See text for further details.

Gravity Survey

Gravity measurements are being collected throughout the region west of Lake Nipigon. Data from this type of survey help infer the density of rock buried in the crust. This is a ground survey and the access to suitable measurement sites is provided by existing access roads. This survey is regional in nature and the increased density of topographically controlled stations is a key component in creating a geological model to better understand the rock formation history. Of interest will be a gravity profile across the interpreted basin forming growth faults, including the Black Sturgeon fault and several poorly defined structures. The complex relationship of these north-south structures with east-trending Archean structures and local development of ovoid PGE-bearing ultramafic intrusions is of high interest.

Geochronology

The age of many rock units within the region is currently poorly understood and determining their age is critical for the development of a comprehensive geological model. Rock samples will be collected during the course of geological mapping. It is planned to collect several pounds of rock material from at least 16 sites. These sites will be determined once geologists have identified the key stratigraphic units and decide which are suitable forgeochronology. Preliminary sampling has been carried out this summer as part of the geological mapping and Lakehead University studies. These preliminary samples will be analyzed over the winter.

Surficial Geochemistry

This project is studying the glacial history of 5 specific areas. Numerous PGE and nickel anomalies were revealed in regional lakes during the recent Operation Treasure Hunt Initiative. The sources of these anomalies are puzzling to the prospectors that followed up the surveys. The objective is to classify the glacial materials and to create case histories of metal transportation in glacial and surficial drainage patterns. The result will be a better understanding of the concentration of metals in lake sediments in the area. This project commenced in June with field sampling being complete by October 2003.

Lakehead University Stratigraphic Mapping and Petrology Studies

Lakehead University is a partner in the LNRGI (Kissin, this volume; Metsaranta, Fralick and Rogala, this volume; Richardson, Heggie and Hollings, this volume). As part of our objective to provide local economic benefit, OPA is providing funding to Lakehead University to support the studies of geology students at the university (Heggie and Hollings, this volume). Much of this work will rely on diamond-drill core from various exploration sites in the region as well as stratigraphic mapping of vertical bedrock outcrops. Detailed sedimentary basin reconstruction and petrochemical differentiation of the mafic and ultramafic intrusions are essential components of the geological interpretation of the Nipigon region.

Compilation

Geographical information system (GIS) compilations of legacy data is underway. This work will compile and index the current large volume of disparate data in the entire LNGRI area and will provide a base for further investigation and research. A large volume of proprietary in-kind data will be integrated with regional maps and databases under a common user-friendly format.

PROGRAM DELIVERABLES

In addition to progress reports made by the geoscientists involved in the different projects at various Ontario Prospectors Association organized symposia in 2003 and 2004, the following deliverables will be released as part of the LNRGI program.

- high resolution airborne magnetic and gamma ray spectrometry maps
- 1:50 000 scale bedrock geology maps and reports for the western Nipigon Embayment
- detailed ground gravity maps with improved resolution
- surficial geochemical case histories and recommended exploration methods
- new age determinations for rocks in the Nipigon Embayment
- digital and paper products from the GIS compilation

A regional summary and interpretation of the combined results will be delivered by the Ontario Geological Survey and Lakehead University staff in subsequent years along with presentations and field excursions at the Institute on Lake Superior Geology (ILSG) conference in May 2005.

The deliverables will be published by the Ontario Geological Survey to ensure high standards of editing and consistent presentation and release of geoscience data.

ACKNOWLEDGMENTS

This project could not have advanced so far so rapidly without the efforts of all the industry collaborators, the staff of the Ministry of Northern Development Mines, the LNRGI Science Advisory Committee, the Implementation Committee, especially the chairpersons of each committee and the administration staff of the Ontario Prospectors Association. Finally, this program would not have happened without the funding from the Northern Ontario Heritage Fund Corporation.

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44. Project Units 03-001 and 03-304. Lake Nipigon Region Geoscience Initiative. Proterozoic and Archean Geology of the South-Central and North Areas of the Western Nipigon Embayment

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INTRODUCTION

The Lake Nipigon Region Geoscience Initiative (LNRGI) is funded through an agreement with the Northern Ontario Heritage Fund Corporation that is administered by the Ontario Prospectors Association (OPA) (Rayner, Lane and Easton, this volume). LNRGI also involves partnerships with the private sector, Lakehead University and several communities in the Lake Nipigon area. The aim of the initiative is to attract mineral industry investment to the Lake Nipigon area (Rayner, Lane and Easton, this volume, *see* Figure 43.1) through bedrock mapping, airborne magnetic and gravity surveys, and targeted surficial geochemical and geochronological studies.

Bedrock mapping of the western Nipigon Embayment will be completed over 2 years at 1:50 000 scale (Rayner, Lane and Easton, this volume, *see* Figure 43.1). Mapping of the northern and central map areas will be conducted under a contract agreement between the Ontario Geological Survey (OGS) and the OPA for the LNRGI, whereas the southern map areas will be mapped by the OGS as part of its commitment of in-kind support to the LNRGI. Geological mapping during this first year of the LNRGI focussed on 1) a north map area around the English Bay complex by MacDonald; and 2) a south-central map area encompassing southern Black Sturgeon Lake and Disraeli Lake by Hart. The bedrock mapping projects also will include interpretation of igneous petrogenesis, stratigraphic analysis, and the development of geological cross-sections, to be undertaken in co-operation with the Lakehead University teams (Kissin, this volume; Metsaranta, Fralick and Rogala, this volume; Richardson, Heggie and Hollings, this volume; Heggie and Hollings, this volume). In addition, the mapping projects will incorporate newly acquired airborne magnetic and gamma-ray data as well as ground gravity data (Rayner, Lane and Easton, this volume), and data acquired by re-logging of diamond-drill core. The LNRGI will also produce a comprehensive geoscience database that will assist mineral exploration for copper, nickel, platinum group elements (PGE) and copper-gold-rich mineralization.

Access and Previous Work

The north map area is located approximately 190 km north of Thunder Bay and west of Lake Nipigon. Access is provided by Highway 527, a series of logging roads extending east and west of the highway, numerous lakes and rivers, and the shore of Lake Nipigon. Previous geological work in the western part of the north map area was conducted by Sage et al. (1974a, 1974b) at a scale of 1:63 360. Geological investigations of the diabase sills and the English Bay complex were completed by Sutcliffe (1986). Bedrock mapping of the shore of Lake Nipigon and adjacent areas, at a scale of 1:50 000, was

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conducted by Sutcliffe and Greenwood (1985a, 1985b). Mineral exploration and prospecting in this area has been sparse, although areas along the west side of the north map area were examined as part of mineral exploration of the Obonga greenstone belt. Corona Gold Corporation completed a diamond-drill program in 1998 for Olympic Dam-style copper-oxide-gold mineralization in the English Bay complex (Wood and Drost 1998). East West Resources Corporation is currently exploring the Havoc, Norwood and Pillar properties that are all located along a north trend through Waweig Lake, lying along an interpreted extension of the Black Sturgeon Lake fault (East West Resources Corporation 2003a).

The south-central map area is located approximately 110 km northeast of Thunder Bay and south of Lake Nipigon. Access is provided by the Black Sturgeon Road, which extends north from highways 11 and 17 at Hurkett, and the numerous logging roads branching to the east and west. Previous geological mapping by Coates (1972) covered the area at a scale of 1:63 360. Mapping, at a scale of 1:50 000, by Sutcliffe (1982) covered the area immediately south of Lake Nipigon, encompassing Black Sturgeon Lake. Mineral exploration and prospecting has been sporadic, with exploration for iron ore in the early 1900s; copper exploration resulting from the discovery of mineralization n[illegible]. Disraeli Lake in 1965 (Coates 1972); and a brief period of exploration for uranium around 1975 (Fenwick et al. 1980). Exploration for PGE mineralization intensified around 1998. The best diamond-drill intersection to date is 1.71 ppm Pt and 1.87 ppm Pd over 2.1 m in basal pyroxenite of the Seagull–Leckie lakes intrusion, which contains 10% disseminated to net-textured sulphide minerals pyrite, pyrrhotite and minor chalcopyrite (Durham 2000).

GENERAL GEOLOGY

Overview

The north map area is underlain by Archean rocks of the Wabigoon Subprovince that are unconformably overlain by Proterozoic sedimentary and volcanic rocks and intruded by Proterozoic diabase sills (Figure 44.1). Several irregularly shaped inliers of Archean rocks occur within the north map area and consist mainly of variously foliated hornblende tonalite, biotite tonalite to granodiorite, gneissic rocks and minor granite to syenite and gabbro. Archean metavolcanic rocks are relatively rare and appear to be correlative with units in the Obonga greenstone belt, except for an area in the north-central portion of the north map area that may represent a separate greenstone belt (*see* Figure 44.1). Two outcrops of possible lamprophyre dikes have been observed to crosscut mafic metavolcanic and gneissic rocks in the Shaw Lake area. The Archean rocks are unconformably overlain by rare occurrences of clastic and chemical sedimentary rocks of the Proterozoic middle to upper Rossport Formation of the Sibley Group. The English Bay complex consists mainly of massive, quartz and feldspar crystal tuffs with a variety of fragment types suggesting a volcanic origin for most of the complex. Several olivine gabbro sills intrude the English Bay complex and have geochemical signatures similar to that of the Kitto peridotite intrusion (Hart 2003) in Kitto Township on the east side of the Nipigon Embayment near Beardmore. Nipigon diabase sills, possibly subdivided into northern sills with normal remnant magnetization, and southern sills that are reversely polarized, intrude all other rock units in the north map area.

The south-central map area is underlain by Archean rocks of the southernmost Wabigoon and Quetico subprovinces that are unconformably overlain by Proterozoic sedimentary rocks and intruded by Proterozoic peridotite intrusions and diabase sills (Figure 44.2). A small area of the southern Wabigoon Subprovince occurs in the south-central map area and consists of metamorphosed and deformed metavolcanic and metasedimentary rocks, with the metavolcanic rocks forming bands less than 1 km wide. The Wabigoon–Quetico subprovincial boundary is interpreted to be located near the southern end of Black Sturgeon Lake. Rocks of the Quetico Subprovince consist of feldspathic wackes and siltstones metamorphosed to upper greenschist to amphibolite grade and intruded by granodiorite to granite dikes

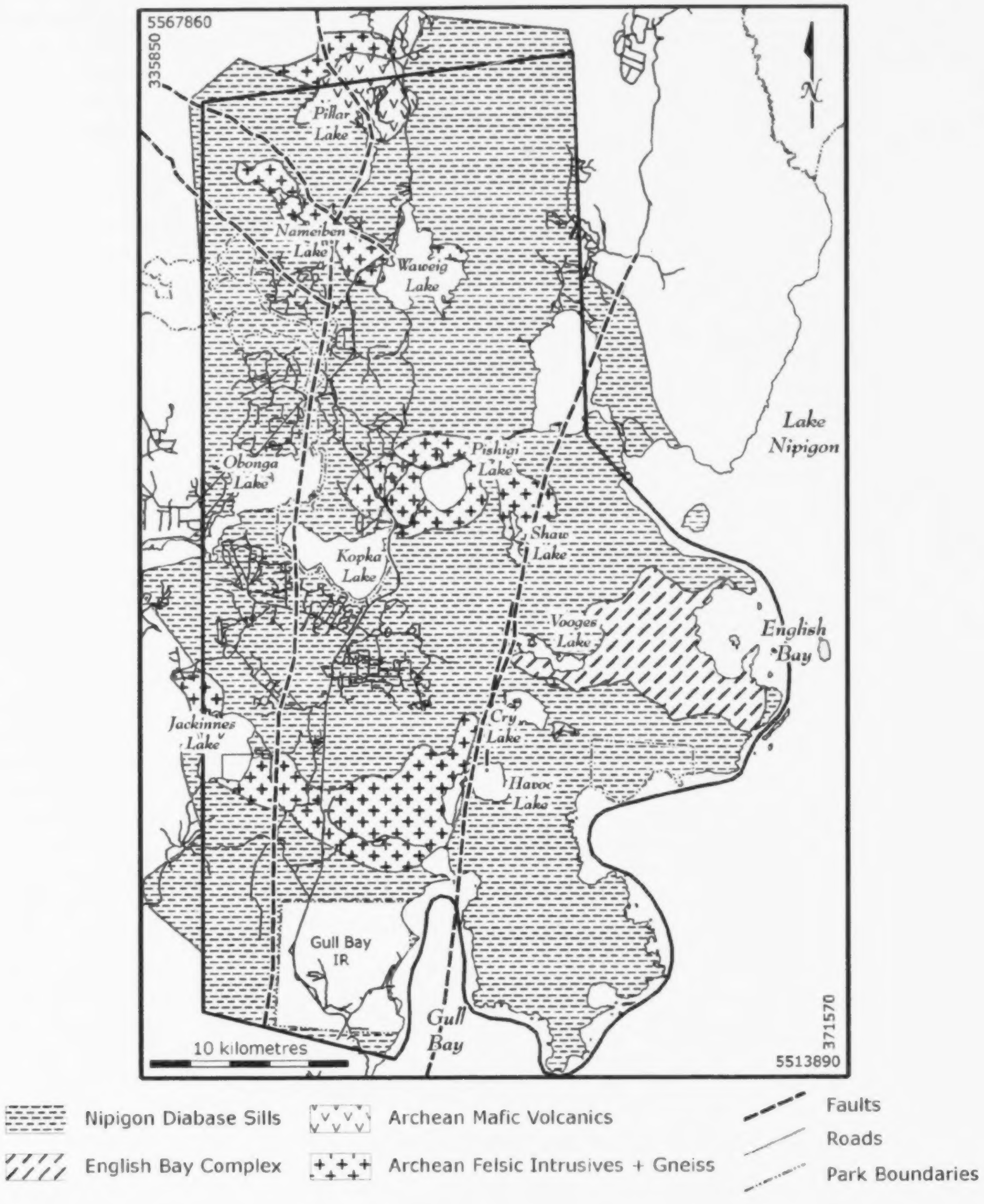
5567860
335850
N
Pillar Lake
Nameiben Lake
Waweig Lake
Obonga Lake
Pishigi Lake
Shaw Lake
Kopka Lake
Lake Nipigon
Vooges Lake
English Bay
Jackinnes Lake
Cry Lake
Havoc Lake
Gull Bay IR
Gull Bay
10 kilometres
371570
5513890
Nipigon Diabase Sills
English Bay Complex
Archean Mafic Volcanics
Archean Felsic Intrusives + Gneiss
Faults
Roads
Park Boundaries

Figure 44.1. Generalized geology of the north map area, located approximately 190 km north of Thunder Bay and to the west of Lake Nipigon.

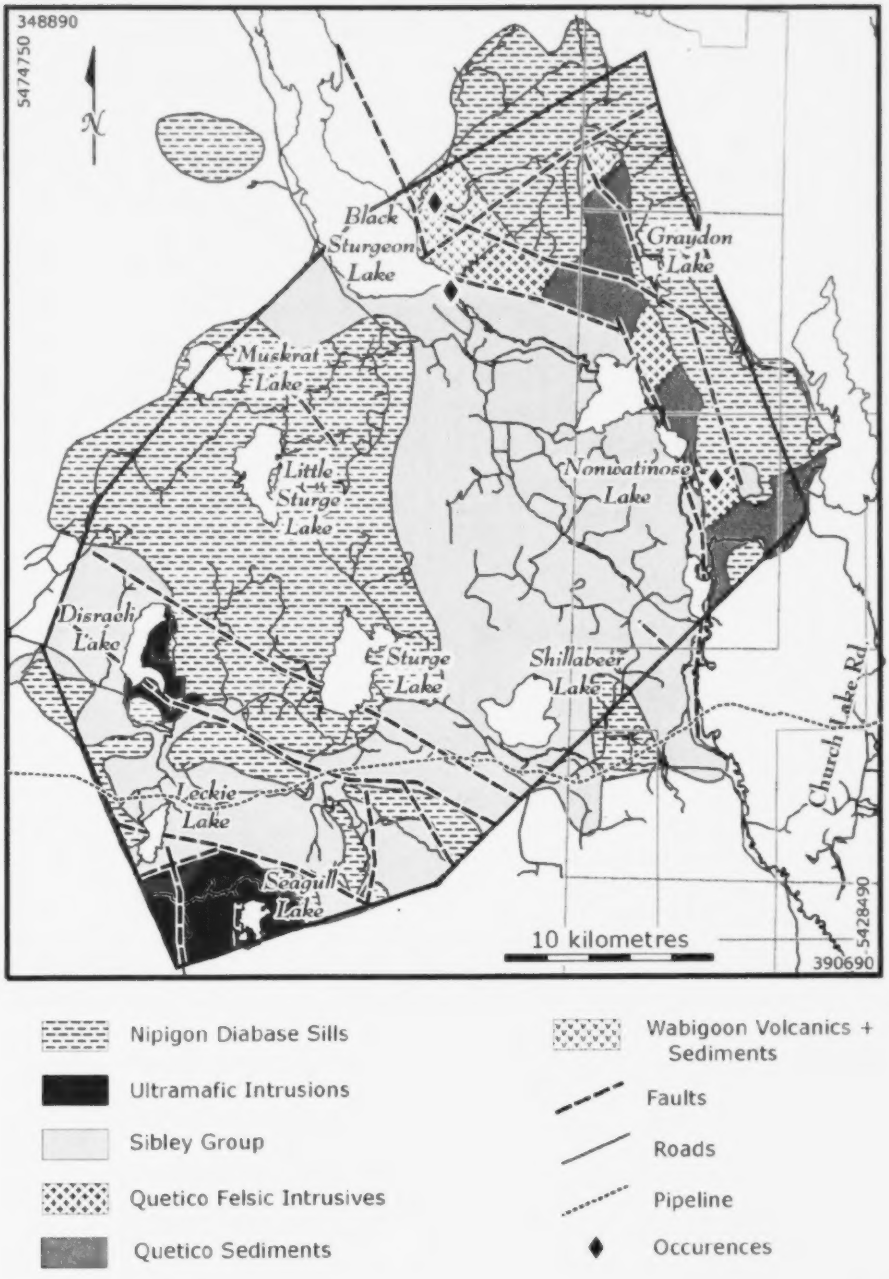
348890
5474750
N
Black Sturgeon Lake
Graydon Lake
Muskrat Lake
Little Sturge Lake
Nonwatinose Lake
Disraeli Lake
Sturge Lake
Shillabeer Lake
Leckie Lake
Seagull Lake
Church Lake Rd.
10 kilometres
5428490
390690
Nipigon Diabase Sills
Ultramafic Intrusions
Sibley Group
Quetico Felsic Intrusives
Quetico Sediments
Wabigoon Volcanics + Sediments
Faults
Roads
Pipeline
Occurences

Figure 44.2. Generalized geology of the south-central map area, located approximately 110 km northeast of Thunder Bay and to the south of Lake Nipigon.

and irregular bodies that form migmatite belts up to 5 km wide. The Archean rocks are unconformably overlain by the Proterozoic Sibley Group, which consists of relatively flat-lying muddy siltstones, sandstones, and dolomites of the Rossport Formation, that are overlain by shales and siltstones of the Kama Hill Formation. Pyroxene peridotite intrusions with olivine gabbro border phases intrude metasedimentary rocks of the Quetico Subprovince and the Sibley Group in the Disraeli and Seagull–Leckie lakes areas. Proterozoic olivine diabase sills, up to 200 m thick, intrude all other units in the area and are chilled against the ultramafic intrusions.

Archean Metavolcanic Rocks

Archean metavolcanic rocks in the north map area occur in 3 widely separated areas that are south of Jackinnes Lake, south of Vooges Lake, and in the north-central portion of the map area on Pillar Lake (*see* Figure 44.1). Two outcrops of felsic metavolcanic rocks in the Jackinnes Lake area consist of a moderately well-foliated, bedded sequence of quartz crystal tuff to fine tuff that are a possible continuation of the Southern assemblage of the Obonga greenstone belt (Percival and Stott 2000). Several sparse outcrops of highly strained mafic metavolcanic rocks occur south of Vooges Lake and are assumed to be the eastern extension of the Obonga greenstone belt. A flat-lying succession of pillowed to massive flows, pillow breccia, and interflow hyaloclastite breccia and hyaloclastite occur toward the north end of Pillar Lake (*see* Figure 44.1). Outcrops generally consist of 3 or 4 alternating, 1 to 2 m thick, pillowed flows that are separated by flow-top breccia or hyaloclastite-rich pillow breccia. Pillows are usually 0.1 to 1 m in diameter with concentric jointing and tortoise shell-like cracks and are separated by interpillow hyaloclastite. These flows have been interpreted to be Archean due to the lack of pristine primary features commonly observed in other Proterozoic volcanic rocks (e.g., the Osler Group).

Intermediate to Felsic Intrusive Rocks

Irregularly shaped inliers of Archean intermediate to felsic intrusive rocks occur in several parts of the north map area: 1) a southeast-trending belt extending from the Collins River to east of Waweig Lake; 2) in the Pishidgi–Shaw lakes area; and 3) a southeast-trending belt from Jackinnes Lake to Havoc Lake (*see* Figure 44.1). Rocks in these inliers consist mainly of variously foliated hornblende tonalite, biotite tonalite to granodiorite; gneissic rocks and minor granite to syenite and gabbro.

A red, hematized syenite to syenogranite body is located on the east shore of Pillar Lake (*see* Figure 44.1). Outcrops of this unit may be similar to those present on the northern edge of the map area and on the Red Granite property of East West Resources (R. Middleton, East West Resources Corporation, personal communication, 2003). The main phase of the red syenite body is a massive, non-foliated, medium- to coarse-grained, inequigranular syenite with less than 10% mafic minerals, less than 5% quartz and locally, less than 1 to 10 cm, irregularly shaped, feldspar-phyric, mafic inclusions. The inclusions appear to be partially assimilated xenoliths. Less common phases include syenitic pegmatite dikes, aplite dikes, and medium-grained, moderately to weakly foliated phases with 15 to 20% amphibole and biotite. A gabbro body exposed along the northeast shore of Pillar Lake is locally crosscut by dikes of weakly to non-foliated red granite to syenite, and is the most likely source of the mafic inclusions in the red syenite. The gabbro is variably foliated and is composed mainly of plagioclase, amphibole and biotite with sporadic trace pyrite. A 2 to 5 m wide fine-grained diabase dike was observed to crosscut the gabbro.

A second syenitic body is exposed on an island in the centre of Waweig Lake. This intrusion consists of a massive, medium-grained, magnetite-bearing syenite to syenogranite and a pegmatitic phase similar to dikes observed on Pillar Lake. The pegmatitic phase is crosscut by a 2 to 3 m wide, fine-grained, diabase dike. The lack of dikes associated with the Nipigon diabase sills in the area suggests that the dike is Archean to Paleoproterozoic and that the syenite is Archean.

Felsic Intrusive Rocks

Several felsic dikes and irregular-shaped bodies intrude the Quetico Subprovince metasedimentary rocks in the south-central map area, resulting in migmatite belts up to 5 km wide. These dikes and intrusive bodies consist of leucocratic pegmatitic granodiorite to granite with minor pegmatitic muscovite-bearing leucogranite dikes. The leucocratic granodiorite to granite bodies are more common to the north, where they form 0.2 to 3 m wide leucosomes. Examples of this texture are exposed along the Church Lake Road, east of Nonwatinose Lake (*see* Figure 44.2). Southeast of Nonwatinose Lake (*see* Figure 44.2), the felsic bodies intrude andulasite-bearing metasedimentary rocks. In this area, a foliated muscovite-biotite granite forms a topographic high, and dikes of pegmatitic muscovite leucogranite intrude the granite and the surrounding metasedimentary rocks. The dikes are commonly 2 to 10 m wide, but may be up to 25 m wide, and commonly intrude along the foliation planes present in the metasedimentary rocks. Graphic intergrowths of tourmaline and quartz are common, with some dikes containing reddish brown garnet, and 1 dike containing plumose muscovite-quartz intergrowths.

Sibley Group

Proterozoic Sibley Group sedimentary rocks in the study areas form a relatively flat-lying stratigraphic sequence consisting of the Channel Island, the Middlebrun Bay, and the Fire Hill members of the Rossport Formation, which are overlain by the Kama Hill Formation (Cheadle 1986). Cyclic mudstone and dolomite or mudstone and sandstone couplets of the Channel Island Member are not exposed in the south-central map area, but are intersected in several diamond-drill holes. In the north map area, Sibley Group sedimentary rocks interpreted to part of the Channel Island Member were observed in 2 locations along the shores of Obonga Lake and in one location east of Waweig Lake (*see* Figure 44.1). Along Obonga Lake, the rocks consist of less than 1 to 3 cm laminated to thinly bedded silty dolostone and massive quartz arenite. East of Waweig Lake, the rocks consist of cyclical, 2 to 3 cm thick, interbedded buff sandy dolostone and red recessive weathering muddy siltstone that overlie a conglomerate or regolith containing cobbles and pebbles of the underlying massive, hematized Archean granite to granodiorite. Stromatolitic dolomitic limestone of the Middlebrun Bay Member is exposed on the southern edge and as rubble in the western portions of the south-central map area. Red, carbonatized, muddy siltstones and mudstones with minor sandstone beds of the Fire Hill Member are the most common sedimentary rocks in the south-central map area, and commonly contain mud cracks, reduction spheres, and solution cavities containing gypsum or calcite. Intraformational conglomerates and/or debris flows containing clasts of mudstone, siltstone, sandstone and dolomitic limestone. These conglomerates mark the transition between the Rossport and Kama Hill formations, and are exposed along the Mawn Road southwest of Shillabeer Lake and on the pipeline at the western edge of the south-central map area (*see* Figure 44.2). Laminated mudstones and medium-bedded massive siltstones of the Kama Hill Formation are observed at higher elevations in the southwestern portion of the south-central map area. The mudstones may contain ripple marks, mud cracks and reduction spots, but lack the carbonate content of the Rossport Formation.

English Bay Complex

The English Bay complex was previously examined as a part of a related doctoral study (Sutcliffe 1986) and mapped by Sutcliffe and Greenwood (1985b) at a scale of 1:50 000. The term English Bay complex, rather than English Bay intrusion or English Bay porphyry, is used in this report, because the body is composed of both volcanic and igneous rocks (North American Commission on Stratigraphic Nomenclature 1983). There are 3 main rock types in the complex: 1) fine-grained, crystal-poor tuff; 2) medium-grained quartz-feldspar crystal tuff to crystal lapilli tuff; and 3) coarse-grained massive quartz and feldspar crystal-rich rock.

The fine-grained, crystal-poor tuffs are typically composed of a fine- to very fine-grained matrix with rare medium-grained, subhedral quartz and feldspar crystals. The tuffs are less than 1 to 3 cm thick and interbedded with the medium-grained crystal tuffs. In diamond-drill core, this rock type occurs as thin beds oriented at the same angle to the core axis, with weak grading from crystal-rich layers into the crystal-poor units. Examples of these tuffs with relatively crystal-poor, recessive weathering layers are exposed along the south side of Vooges Lake (Photo 44.1).

The medium-grained quartz-feldspar tuff to crystal lapilli tuff appear to be the most abundant rock type in the complex. Typically, these rock types are massive to bedded, containing 40 to 65% quartz and feldspar crystals in a red to purple hematized or yellow green sericitized matrix. Subhedral to subangular, broken, light blue quartz crystals, ranging from less than 1 to 4 mm, compose 20 to 35% of the rock. Feldspar crystals are less than 1 to 5 mm in diameter, euhedral to subangular, commonly segmented or broken along cleavage planes, and compose 30 to 45% of the rock. Cognate fragments and, to a lesser

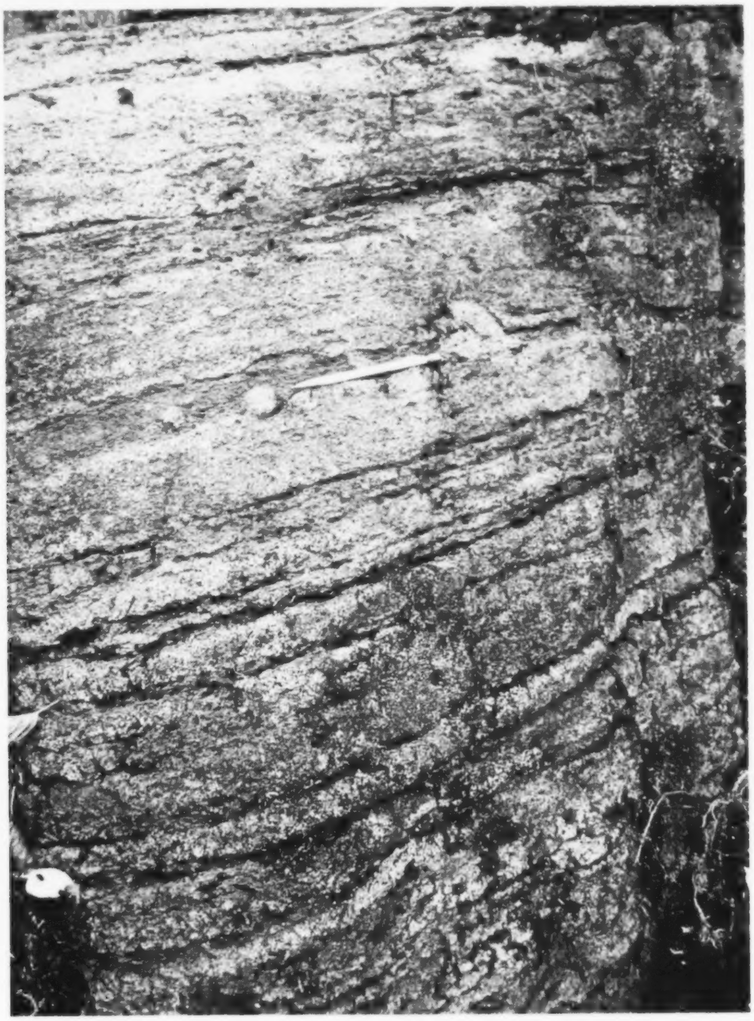

Photo 44.1. Thinly bedded quartz crystal tuff of the English Bay complex containing rare lapilli (indicated by pen) that are similar in composition to the tuff. Subsequent hematization of varied intensity preferentially follows some beds. Outcrop is located on the south shore of Vooges Lake. Pen is 12 cm long. Location: UTM: NAD83, Zone 16, 356193E, 5535000N.

extent, accidental fragments appear to be limited to specific geographic areas or stratigraphic intervals within the complex. Cognate fragments may consist of quartz-feldspar crystal-rich tuff, fine-grained crystal-poor tuff, and pumice. Quartz-feldspar crystal-rich blocks are lapilli to block size, subrounded to subangular, and similar in composition to the material in which it occurs. Examples of these fragments are exposed along the logging road south of Vooges Lake and locally observed on an island in English Bay. Crystal-poor fragments are lapilli-sized, subrounded to subangular fine-grained aphyric to crystal-poor material similar in composition to the matrix of the quartz-feldspar crystal tuff. The best examples are observed in the diamond-drill core and along the shore of English Bay and the adjacent islands. Black to grey or green grey, less than 1 to 4 cm fragments with wispy laminations or layering resembling flattened pumice tubes may be either cognate fragments or juvenile fragments similar to those described by Sutcliffe (1986). This fragment type appears to be limited to outcrops on several islands in English Bay as well as to intervals within Corona Gold Corporation diamond-drill core that may be stratigraphically higher in the complex. Accidental fragments consist of 2 to 5 cm quartz-rich fragments that may represent gneissic tonalite basement, and dark grey to grey-green, centimetre-sized fragments that may be metavolcanic in origin.

The coarse-grained, brick red, massive rock type is composed of up to 70%, 0.2 to 1 cm subhedral quartz crystals and 0.2 to 1.5 cm subhedral to euhedral, typically zoned feldspar crystals with an absence of fragments. Examples with greater than 65% crystals resemble a granite, but local variations in crystal size and content over 5 to 50 cm intervals suggest that this unit may be layered or bedded. This rock type is observed in diamond-drill core and one outcrop south of Redstone Point on Lake Nipigon.

Mafic to Ultramafic Intrusive Rocks

Ultramafic intrusions consisting of pyroxene peridotite with olivine gabbro and monzogabbro border phases occur in the Disraeli and Seagull–Leckie lakes areas in the southwest part of the south-central map area (*see* Figure 44.2). These peridotites intrude Sibley Group and Quetico Subprovince rocks and are, in turn, intruded by diabase sills. The peridotites are medium to coarse grained and massive, consisting of olivine and pyroxene with 1 to 2% reddish brown mica. In diamond-drill core, the peridotites have occasional ophitic intervals consisting of very coarse-grained pyroxene oikocrysts, with the best examples observed in the Seagull intrusion. Petrographic examination indicates that the peridotites are a mixture of wehrlite and lherzolite with orthocumulate to mesocumulate textures (Seagull intrusion: Osmani and Rees 1998; Disraeli intrusion: Bowdidge 1999).

The olivine gabbro forms an irregularly distributed border phase that is medium grained and massive consisting of pyroxene, olivine and plagioclase, with 1 to 2% reddish brown mica. Contacts between the peridotite and olivine gabbro observed in diamond-drill core are generally gradual transitions in grain size and olivine and plagioclase content, but interlayering of the 2 rock types is present in a few of the Seagull diamond-drill holes.

Irregular bands of monzogabbro or granophyre are distinguished by the occurrence of pink feldspar, and usually occur in the olivine gabbro near contacts with the country rock. The monzogabbro ranges from fine to medium grained and generally resembles the olivine gabbro, but some very coarse-grained examples have relatively sharp contacts with the olivine gabbro. Preliminary lithogeochemical results indicate that the presence of pink feldspar correlates with elevated K_2O values, supporting an interpreted origin as a result of the assimilation of Sibley Group sedimentary rocks (Hart 2003). The geochemistry for the Disraeli and Seagull intrusions also indicates that the 2 intrusions are comparable and that the olivine gabbro border phases probably formed as a result of fractional crystallization from a peridotite parent magma (Hart 2003). Nipigon diabase has an irregular, polygonal-textured chilled contact against the olivine gabbro of the Seagull intrusion, north of Seagull Lake.

Diabase Sills

Generally flat-lying, but gently undulating, Proterozoic Nipigon diabase sills intrude all other rock units in both map areas. Davis and Sutcliffe (1985) obtained a U/Pb age of 1109+4/–2 Ma, based on zircon and baddeleyite from 2 sills from the Nipigon Embayment. The sills are usually composed of massive, medium- to coarse-grained feldspar and pyroxene, with trace to 3% fine-grained olivine and 1 to 2% magnetite. Occasional intervals of diabase rich in gas cavities, leucocratic, pegmatitic, magnetite porphyritic or ophitic diabase are also present. These changes in texture represent a crude downward sequence from the upper contact of the sill, similar to the generalized section suggested by Sutcliffe (1986). Leucocratic diabase is relatively rare and recognition is dependent on the lack of weathering on the outcrop. Pegmatitic diabase is common toward the top of the sills and consists of irregular patches or dikes of coarse-grained white to pink feldspar and actinolite up to 6 cm in length. Although there is no evidence of alteration in the adjacent diabase, the presence of pink feldspar in some patches suggests some interaction with the country rock has occurred. Ophitic diabase, with pyroxene oikocrysts up to 2 cm in diameter, occurs at more than one stratigraphic level within the sills and has been observed close to the top of the sills, with one example hosting pegmatitic patches. In another example, from the lower portion of the sill between Sturge and Little Sturge lakes where diamond-drill hole SR02-01 is located, intervals of ophitic diabase are interbanded with massive coarse-grained diabase suggesting a crude layering. The magnetite-porphyritic diabase is not porphyritic, but rather, is a field term that describes a diabase containing coarse-grained magnetite that occurs toward the top of the sills. Most sill exposures consist of massive, medium- to coarse-grained diabase, although weathering often hinders identification of the other textures.

Most diabase sill contacts are polygonally jointed and aphanitic, with a varied content of fine-grained feldspar phenocrysts that may form glomeroporphyritic masses. Diabase in contact with the Quetico Subprovince metasedimentary and felsic intrusive rocks may contain subangular to subrounded, pebble- to boulder-sized xenoliths of country rock. Generally at the contacts, the diabase increases in grain size to fine to medium grained over less than a metre, with generally no evidence of assimilation of country rock. A more complex contact relationship exists in some areas along either the upper or lower contacts of the sills, and appears to correlate with intrusion into Sibley Group sedimentary rocks. Diabase with abundant gas (miarolitic?) cavities may occur along some contacts. These cavities are irregularly shaped, 0.25 to 0.5 cm cavities containing black biotite or amphibole and less commonly wollastonite, along the upper sill contact in the area east of Graydon Lake (*see* Figure 44.2). Layering, consisting of a variation in grain size from fine to very fine grained over 10 to 20 cm, is also present in the same area. Diabase containing gas cavities is also exposed along the lower contact of a sill south of Muskrat Lake along the northern projection of the Fox Mountain dike. This cavity-rich diabase is overlain by a zone containing irregularly shaped clots of amphibole up to 10 cm in length and a second zone of numerous 0.5 to 1.5 cm xenoliths of quartz and feldspar. Stratigraphically above these zones are 3 subhorizontal irregular bands of very coarse-grained pink feldspar and amphibole up to 5 cm thick. The gas cavities may be the products of either later magmatic fluids; the result of the assimilation of volatiles from adjacent country rocks particularly the carbonate-rich units of the Sibley Group or miarolitic cavities. A preliminary interpretation is that these textures represent a reaction zone with volatile-rich Sibley Group sedimentary rocks along the lower contact of the sill that was subsequently intruded by a second diabase sill.

The Fox Mountain dike forms a 50 to 90 m high, approximately 10 km long, north-trending ridge located east of Disraeli Lake. The diabase at the top of the ridge is medium- to coarse-grained, massive, olivine gabbro diabase, with minor coarse-grained, magnetite porphyritic diabase. Another Nipigon diabase sill has chilled contacts with the Fox Mountain dike and, although not well exposed, 2 of the 3 contacts appear to be flat lying, suggesting that the Fox Mountain dike may be a partly eroded sill. Preliminary lithogeochemical sampling in 2002 indicates that the Fox Mountain dike has the same geochemical characteristics as the other Nipigon sills (Hart 2003).

Structure

The Quetico Subprovince metasedimentary rocks in the south-central map area have an approximately 060° schistosity. Isoclinal folding of the beds is evident. Felsic intrusive rocks generally follow the trend of the schistosity and some narrow felsic dikes are boudinaged. The Wabigoon–Quetico subprovincial boundary is indistinct and is tentatively located toward the southern end of Black Sturgeon Lake, and as noted by Sutcliffe (1982), it is not defined by a major structure. The position of this boundary is based on the correlation of regionally continuous iron formations that can be traced by airborne geophysical magnetic surveys (Gupta 1991) to the metasedimentary sub-belts of the Beardmore–Geraldton greenstone belt. In the north map area, metavolcanic rocks of the Obonga greenstone belt strike roughly northeast. The Archean mafic metavolcanic rocks in the Pillar Lake area are apparently flat lying.

Proterozoic units are generally subhorizontal, with the Sibley Group sedimentary rocks dipping 5 to 15° east and striking approximately northwest. This results in an up-stratigraphic progression from east to west in both map areas. Outcrops of the Sibley Group are rare in the north map area, as well as to the east of the Black Sturgeon River in the south-central map area. Their occurrence and distribution is most likely controlled by a combination of topographic lows in the original Archean surface and by preservation by the overlying Nipigon diabase sills. The diabase sills are generally flat lying to gently undulating, with the current distribution of diabase sills probably the result of varied degrees of erosion controlled in part by regional structures. Sill contacts locally dip up to 30° along a north trend, with an example of a dipping chilled contact against Quetico Subprovince metasedimentary rocks exposed in the area north of Graydon Lake (*see* Figure 44.2).

Jointing in the diabase sills may be either arcuate or linear. The arcuate joints vary in strike direction by up to 70° and are commonly observed on horizontal surfaces. These joints are interpreted to be cooling fractures and may form networks of crudely polygonal joint sets. In a few locations along the Church Lake Road, southwest of Graydon Lake, the polygonal joints display roughly concentric cooling fractures (*see* Figure 44.2). Linear joints appear to be associated with late structures that transect the cooling fractures and are interpreted to be related to regional structures.

There appears to be 3 major fault trends in the map areas: northeast, northwest and north trending. The presence of Sibley Group sedimentary rocks, diabase sills and glacial deposits obscures many of the details of these structures. The northeast-trending faults occur in the south-central map area and are subparallel to the regional fabric of the Quetico Subprovince. Northwest-trending faults correlate with structures observed in the central Wabigoon Subprovince, and may cause a right lateral offset of the north-trending faults. A set of north-trending faults appears to be *en échelon*, resulting in the formation of an asymmetric basin or half-graben approximately 20 km wide (Coates 1972). These north-trending faults may be an expression of the failed arm of the Midcontinent Rift (e.g., Franklin et al. 1980). The Black Sturgeon fault is the most prominent of these north-trending structures forming the eastern boundary of the half-graben. Vertical displacement along the Black Sturgeon Fault has been estimated to be 213 to 305 m by Coates (1972) and 420 m by Sutcliffe (1986) in the south-central map area. Lateral displacement along the Black Sturgeon Fault is not conclusive, but may by on the order of 1 km in a sinistral direction, based on the displacement of the iron formation in the Wabigoon Subprovince. There is little information with which to control estimates of the magnitude of the vertical and lateral offsets along this north-trending fault system in the north map area.

ALTERATION

Intrusion of the peridotite, and occasionally the diabase, into adjacent Sibley Group rocks results in the formation of a hornfels that may extend for up to 100 m from the contact of the intrusions. The mudstone beds within the Sibley Group form a light green, mauve, reddish grey to light grey banding composed of a tremolite- and carbonate-rich mineral assemblage. Dolomite-rich beds form white to buff marbles. Orbicular texture in 3 to 5 cm wide zones occur along some sill contacts, and 0.2 to 0.5 cm tremolite orbs were observed in one outcrop. Wollanstonite, NaCa-zeolite minerals, actinolite and/or tremolite, or actinolite and feldspar occur along joints and fractures in the diabase sills near contacts with Sibley Group rock, and are possibly a result of reaction with the sedimentary rocks.

Hematite alteration in the south-central map area is commonly associated with late fracturing in both Archean and Proterozoic rocks. Metre-scale zones of intense hematization occur in faulted portions of the peridotite of the Seagull intrusion, resulting in distinctive dark-red pyroxene phenocrysts. A good example of the hematization occurs in diamond-drill hole WM98-04 drilled by Avalon Ventures Limited, located in the northwest part of the intrusion. Intense hematization also was observed in a leucogranite intruding the Quetico Subprovince metasedimentary rocks southeast of Graydon Lake, along the Church Lake Road (*see* Figure 44.2). There, hematite and specular hematite occurs along a northeast-trending shear zone on the south side of the leucogranite. Moderate to intense hematite mineralization also occurs along the east side of Black Sturgeon Lake, and along the Black Sturgeon River in the Nonwatinose Lake area. This mineralization occurs as disseminated hematite and fracture-fillings of specular hematite, with examples of the specular hematite associated with uranium mineralization in the Black Sturgeon Lake and Split Rapid Dam occurrences. The hematization is generally associated with north-trending structures and may be a useful indicator of the north-trending fault systems in areas with limited bedrock exposure.

Hematite alteration in the north map area appears to be localized along a possible north-trending structure that extends from the southwest tip of Jackinnes Lake to north of Pillar Lake and within the English Bay complex (*see* Figure 44.1). The structurally controlled hematization affects several of the rock units including the red syenite and mafic metavolcanic rocks north of Pillar Lake, and the felsic metavolcanic rocks south of Jackinnes Lake. In the red syenite, earthy hematite is weakly to moderately disseminated through the rock and commonly occurs in combination with specular hematite in fractures or veins. The flat-lying Archean mafic metavolcanic rocks typically display weak sericite and weak to moderate, patchy hematite alteration, particularly within interpillow hyaloclastite and flow-top breccia units. Alteration intensity appears to increase with proximity to the inferred, north-trending structure. The Archean felsic metavolcanic rocks south of Jackinnes Lake are weak to moderately pervasively sericitized and are overprinted by a similar patchy to pervasive and fracture-controlled hematization alteration.

The English Bay complex displays a complex alteration history with 3 prominent styles of alteration that have diffuse boundaries. These 3 types are 1) a red, moderate to strong pervasive hematization of the groundmass; 2) a mauve to dark purple, locally moderate to strong pervasive hematization of the groundmass; and 3) a localized, weak to moderately intense sericite alteration. The pervasive hematization is more common in the coarse-grained, massive rock types and the medium-grained quartz-feldspar crystal tuffs, with patches of more intense alteration where the feldspars are difficult to distinguish from the groundmass. The mauve to purple hematization occurs as a) purple patches with diffuse boundaries; b) purple haloes around veins; c) specular vein-fracture fillings; and d) preferential and/or selective alteration of a bed or beds. Multiple episodes of sericite alteration are evident with the most significant being vein-fracture–controlled haloes and selective alteration of fine-grained, crystal-poor and/or recessive weathering beds. A late vein-controlled epidote with possibly quartz and rare specular hematite or purple fluorite may represent a fourth alteration style. Further work is needed in order to unravel the complex alteration history.

MINERALIZATION

Platinum group element mineralization in the Nipigon Embayment is associated with the occurrence of sulphide minerals in the peridotite intrusions, as at Seagull Lake (Durham 2000) and Kitto, in the Beardmore area (East West Resources Corporation 2003b). The peridotite is commonly deeply weathered and may be capped by a black sand regolith tens of centimetres thick, so that these zones are only rarely observed in outcrop. As no sulphide mineralization was observed to be associated with either the peridotites or diabase sills and all analytical work is pending, it would be premature to comment on the mineral potential of the 2 map areas.

A set of 2 to 10 m wide, pegmatitic, muscovite leucogranite dikes intrude the Quetico Subprovince metasedimentary rocks southeast of Nonwatinose Lake (*see* Figure 44.2). Graphic intergrowths of tourmaline and quartz, the presence of reddish brown garnet, and plumose muscovite-quartz intergrowths all may indicate that these dikes are related to a fertile granite and, therefore, have the potential to host rare-element mineralization (Breaks, Selway and Tindle 2003). Further investigation of these dikes for their mineral potential is warranted.

Sulphide mineralization was observed in a 30 cm wide silicified zone containing up to 20% disseminated pyrite, along the schistosity of a Quetico Subprovince andulsite schist located southeast of Nonwatinose Lake, east of the Black Sturgeon River (*see* Figure 44.2). This mineralization occurs in an area intruded by several pegmatitic leucogranite dikes. Assay results from this occurrence are pending, but further work for base and precious metals in this area is recommended.

There are 2 uranium occurrences in the south-central map area, the Black Sturgeon Lake and the Split Rapid Dam occurrences. The Black Sturgeon Lake uranium occurrence, discovered by Sutcliffe (1982), is still exposed in an area stripped by Uranez Exploration (*see* Figure 44.2) (Scott 1987). At the Black Sturgeon Lake occurrence, northeast-trending metawackes, iron formation, and amphibolite are intruded by a north-trending pegmatitic leucogranite dike. These units are cut by north-trending fractures that are subparallel to the north-trending faults of the Black Sturgeon fault system. The fractures contain hematite, magnetite, calcite, pitchblende and uranopilite, and an age for the mineralization of 1090±25 Ma was reported by Scott (1987) based on communication with personnel of the Geological Survey of Canada. Varied amounts of disseminated pyrite, chalcopyrite and pyrrhotite are present in the adjacent iron formation. The Split Rapids Dam uranium occurrence is located near the southeast corner of Black Sturgeon Lake (*see* Figure 44.2) and is hosted by a breccia that resembles the intraformational conglomerate and/or debris flows present in the upper Rossport Formation, but which also has been interpreted as a fault breccia (Scott 1987). Mineralization consists of pitchblende associated with epidote, calcite and hematite. Assay results for both occurrences are pending.

Hematite alteration is common in both the south-central and north map areas and is also common in both Archean and Proterozoic rocks and associated with north-trending structures. The association of hematite and specular hematite with uranium mineralization in the Black Sturgeon Lake and Split Rapid Dam occurrences indicates that the addition of iron may be more than a simple alteration event. However, the origin of the hematite is not clear at this stage, and there is the possibility of more than one hematite alteration event as suggested by the complex alteration history in the English Bay complex. Further work is required to understand the timing and number of hematite alteration events and their metallogenic significance.

DISCUSSION

The flat-lying mafic metavolcanic flows located near the northern edge of the north map area are interpreted to be Archean due to the lack of pristine primary features that are commonly observed in other Proterozoic volcanic rocks. The geographic location of these flows makes correlation with the Obonga greenstone belt (2855 to 2726 Ma; Tomlinson et al. 1998) difficult and suggests that these flows may represent a previously unrecognized greenstone belt. Although these flows are interpreted to be Archean, there is a possibility that they may be Paleoproterozoic, possibly related to the same igneous event that formed the English Bay complex ($1536^{+10}/_{-2.3}$ Ma; Davis and Sutcliffe 1985). Field evidence suggests that these flows form a sequence approximately 10 to 15 m thick overlying Archean plutonic rocks. These flows are a candidate for geochronologic analyses.

Geochemical sampling completed in 2002 indicates that there are 3 geochemically distinct mafic to ultramafic intrusions in the Lake Nipigon area: 1) the diabase sills; 2) the Disraeli, Seagull and Hele peridotite intrusions; and 3) the Kama Hill–English Bay olivine gabbro sills and the Kitto peridotite intrusion (Hart 2003). The Nipigon sills have lower Th/Yb ratios than the other 2 units, and the peridotites are distinguished from the olivine gabbro sills by lower Th/Ta ratios, but high Gd/Yb ratios. A preliminary interpretation suggests that the peridotites are probably an early rift-related alkalic magma, whereas the transitional alkalic–calc-alkalic chemistry of the olivine gabbro sills may be a result of crustal contamination, rather than a tectonic signature. Previous work by Sutcliffe (1986) indicated that there is little variation in the chemistry of the sills across the Lake Nipigon area, with the possible exception of higher iron-rich sections in the D'Alton Lake and Kopka River sills. This high iron content may correlate with a suggested normal polarity for the northern diabase sills (R. Middleton, East West Resources Corporation, personal communication, 2003). Preliminary lithogeochemical sampling also indicates that the Keweenawan diabase sills in the Lake Nipigon and Crystal Lake areas are 2 distinct geochemical groups (Hart 2003). The Logan diabase sills located south of Thunder Bay have higher TiO_2, Zr/Y, and La/Yb than do the Nipigon sills that occur north of Thunder Bay. This difference in the geochemistry of the Nipigon and Logan diabase sills is similar to the observed geographic distribution of geochemical differences in volcanic rocks from a number of flood basalt provinces (e.g., Mantovani et al. 1985). Additional work is required to determine the regional extent of these geochemical differences.

Sill thickness is difficult to determine as the upper and lower sill contacts are never observed in the same stratigraphic section. Exposed sills appear to range from 50 to 80 m thick with the lower portions of the hills commonly consisting of Wabigoon Subprovince, Quetico Subprovince or Sibley Group rocks. Thick sills have been intersected in diamond-drill holes, with an approximately 200 m thick sill in diamond-drill hole SR02-01 drilled by Teck Cominco Limited, although 0.2 to 15 m thick sills are also common in some of the diamond-drill holes. There are at least 2 major sills in the region, as originally suggested by Sutcliffe (1986). More major sills may be present, however, and simple horizontal correlation may not be possible without the discovery of a distinctive geochemical signature between the different major sills. The relationship between the major and minor sills is not known and there are a number of possible interpretations. These include 1) the minor sills are the leading edge of a major sill; 2) the minor sills are branches from major sills that are following less favourable structures; or 3) the minor sills represent separate, lower volume, magma pulses.

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45. Lake Nipigon Region Geoscience Initiative. Sulphide Saturation Mechanisms in Diabasic and Gabbroic Intrusions in the Nipigon Embayment

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INTRODUCTION

Recent discoveries of potentially exploitable occurrences of copper-nickel-platinum group element (PGE) minerals in Proterozoic mafic intrusions in the Lake Nipigon region, for example, the Seagull, Disraeli and Hele properties, are the motivation for this project. This study seeks to determine the mechanisms causing sulphide saturation within the magmas of the intrusions. Although the causes of the distribution of PGE minerals in layered intrusions may involve such processes as the action of deuteric fluids, hydrothermal processes or metamorphism, there is wide agreement that the ultimate source of the PGEs is magmatic (Naldrett 1993). Working from this initial assumption, it is possible to follow a line of investigation into the process of mineralization.

Experimental and theoretical studies on the behaviour of PGEs in mafic magmas have demonstrated that PGEs as well as chalcophile elements are strongly partitioned into a co-existing, immiscible sulphide melt. The foregoing studies, as well as field-based observations on tholeiitic layered intrusions, indicate that the following factors lead to the formation of PGE-rich horizons (Naldrett 1993):

1. the parental magma must be initially undersaturated with respect to sulphur
2. the parental magma must be enriched in PGEs, or PGE enrichment must have been developed during fractional crystallization of the magma
3. initial production of an immiscible sulphide melt must be the result of a process that produces a high silicate–sulphide melt ratio

According to Boudreau and McCallum (1992), a gabbro cumulate crystallized from a sulphur-saturated magma should contain more than 400 ppm S. Thus, following a methodology employed by Miller (1999), comparison of sulphur content with copper, nickel, gold, platinum and palladium will provide information on the mechanism of mineralization.

RESULTS

The approach described above was applied to analytical data obtained from Wolf Mountain Joint Venture diamond-drill hole WM00-01, which penetrated the Seagull intrusion completely at a depth of 720 m and passed into underlying Quetico Subprovince metasedimentary rocks to a total depth of 820 m. A summary of the rock types encountered in the diamond-drill core is given in Table 45.1, based on diamond-drill core logs. A more detailed petrographic description of diamond-drill hole WM00-01 is given in Heggie and Hollings (this volume).

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Analyses for Cu, Ni, S, Au, Pd and Pt are plotted against depth of the diamond-drill hole in Figures 45.1 and 45.2. In Figure 45.1, the dashed vertical line at 0.4% S (400 ppm) indicates the theoretical threshold for sulphur saturation of the magma.

Table 45.1. Summary diamond-drill core log of WM00-01.

Depth (m)	Rock Type	Notes
0 – 46	Peridotite	
46 – 114	Olivine gabbro sill	Late Nipigon sill intruding Seagull intrusion
114 – 571	Peridotite	
571 – 606	Dunite	Anomalous PGEs within this zone
606 – 681	Peridotite	
681 – 720	Gabbroic pyroxenite (lherzolite)	
720 – 820	Quetico Subprovince metasedimentary rocks	

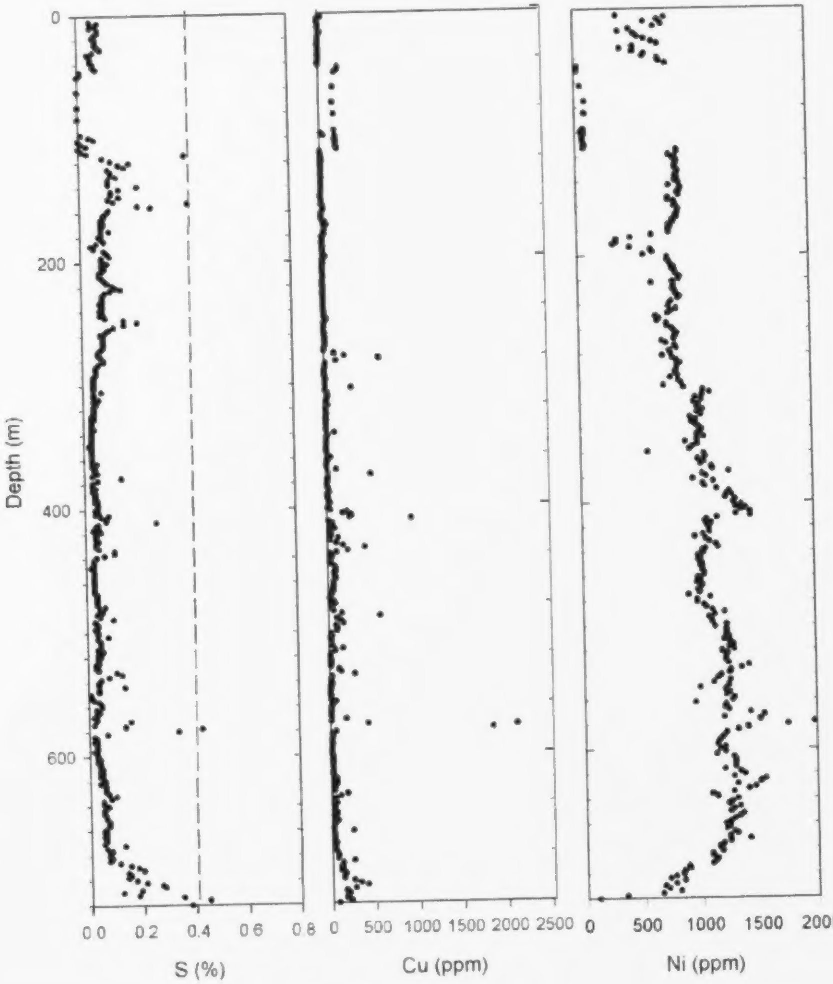

Figure 45.1. Variation in sulphur (S), copper (Cu) and nickel (Ni) content with depth in diamond-drill hole WM00-01. The dashed line in the S versus depth plot denotes sulphur saturation at 400 ppm.

DISCUSSION

Examination of Figure 45.1 reveals that sulphur saturation in WM00-01 occurred for about a 10 m interval at the base of the Seagull intrusion; for a similar interval near 580 m; and at 2 intervals at roughly 120 and 140 m. A spike at 420 m is below the 400 ppm threshold, but appears nevertheless to be significant. The significance is seen in that at both the 420 m and 580 m depths, there are marked increases in copper and nickel content, corresponding to fractionation of these metals into a sulphide melt. The sulphur spike seen at the base of the intrusion is not accompanied by an increase in copper and nickel. In fact, nickel is anomalously low relative to that in the remainder of the intrusion, with the exception of the olivine gabbro sill. This texturally and compositionally distinctive zone may be a chill zone in which crystallization of olivine was suppressed in a relatively unfractionated magma, accounting for the low nickel content and lack of significant copper enrichment. The apparent sulphur saturation at 120 and 140 m does not correlate with copper and nickel enrichment and is unexplained at present.

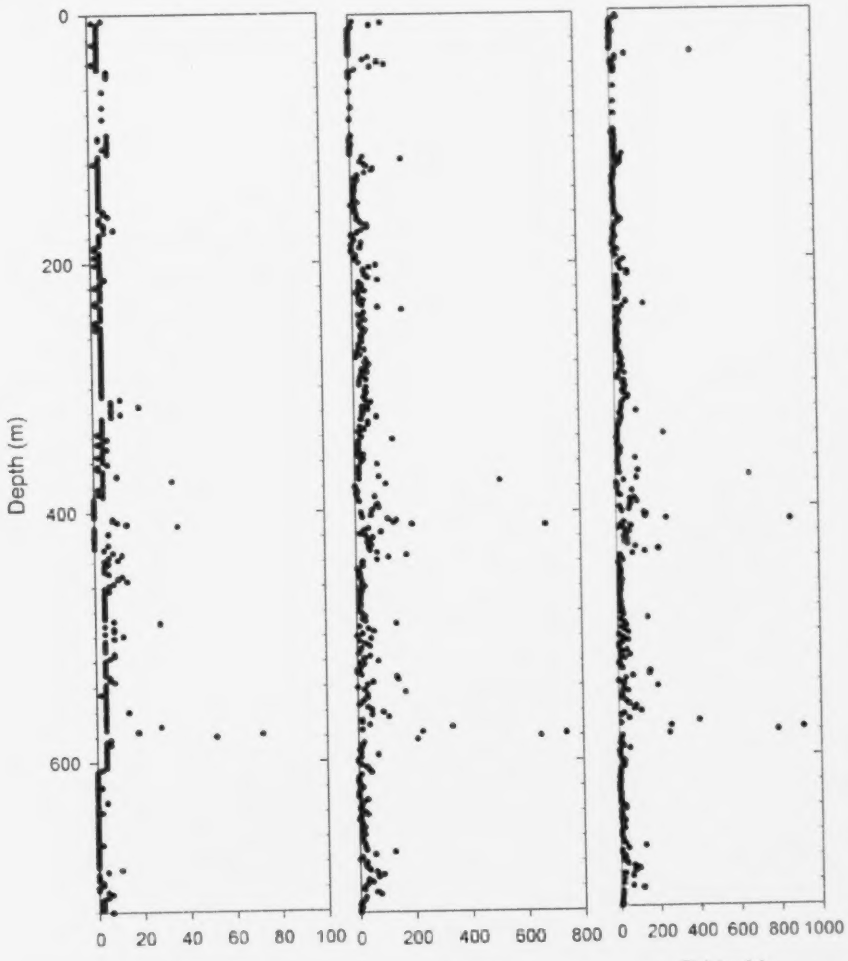

Figure 45.2. Variation in gold (Au), platinum (Pt) and palladium (Pd) with depth in diamond-drill hole WM00-01.

Figure 45.2 shows that sulphur saturation at the 420 and 580 m depths is accompanied by significant spikes in gold, palladium and platinum at and above these levels. The sulphur-saturated base of the intrusion shows no significant increases in the contents of these precious metals, supporting the explanation offered above. Unpublished data obtained from J.M. Franklin (J.M. Franklin, Franklin Geoscience, personal communication, 2003) indicate that the sulphur isotopic compositions of the sulphide minerals at the base of the intrusion, largely consisting of pyrrhotite, are nearly identical with those of sulphide minerals found in the underlying Quetico Subprovince metasedimentary rocks. Thus, assimilation of sulphur in this basal zone appears to have occurred.

Although no Cu-Ni-PGE enrichment in the basal sulphur-saturated zone of diamond-drill hole WM00-01 is present, diamond-drill holes to the west of this hole have intersected PGE enrichment at the base of the intrusion. This differing result may be due to pooling of sulphide melt in these areas, accompanied by collection of Cu, Ni and PGEs. In these diamond-drill holes, however, sulphur-saturation and PGE enrichment is not seen at higher levels in the intrusion. Work continues into the investigation of these problems.

ACKNOWLEDGMENTS

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46. Lake Nipigon Region Geoscience Initiative. Combined Lithostratigraphic Modelling of the Sibley Group and Mafic Intrusive Rocks of the Nipigon Embayment

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INTRODUCTION

Comprehending the three-dimensional lithostratigraphy of the Nipigon Embayment is critical as a mineral exploration guide, a tool in the interpretation of regional igneous geochemical data, and in providing a framework promoting the understanding of mechanisms of sill emplacement. Currently, a detailed model of the regional stratigraphic relationships among the Archean and Mesoproterozoic (Sibley Group) host rocks and the Nipigon sills is lacking. The purpose of this article is to summarize the preliminary results of a regional compilation of diamond-drill core and outcrop data from the Sibley Group and the mafic and ultramafic intrusions comprising the Nipigon Embayment. Through this and continuing work, a viable model for the overall lithostratigraphic relationships between the Sibley Group and Midcontinent rift related mafic intrusive rocks of the region will be resolved.

This project was initiated and funded as part of the Lake Nipigon Region Geoscience Initiative (LNRGI). To this point, field work has involved mainly observations from vertical outcrop sections of diabase intrusions and the Sibley Group sedimentary rocks that host the intrusions in the various portions of the LNRGI study area. During the field season, particular focus was paid to the southern boundaries of the area, but also, to a lesser extent, outcrops were visited on Lake Nipigon. Logging of diamond-drill core stored at the Ministry of Northern Development and Mines off-site, remote diamond-drill core storage facility and drill core library in Thunder Bay was also undertaken.

GENERAL STRATIGRAPHY OF THE SIBLEY GROUP

The Sibley Group consists of relatively flat-lying Mesoproterozoic sedimentary rocks that rest unconformably on Neoarchean metavolcanic and intrusive rocks, Quetico Subprovince metasedimentary rocks and the Paleoproterozoic Animikie Group. Outcrops of the Sibley Group are found mainly in an area bounded to the south by Lake Superior and to the north by Lake Nipigon (Figure 46.1). The current eastern boundary of exposure is slightly east of the Town of Rossport. In the west, outcrops of Sibley Group rocks extend as far as the west shore of the Sibley peninsula. Scattered outliers of the Sibley Group are also found at various locations further north along the shore of Lake Nipigon, such as at Redstone Point. Diamond-drill core data confirms that the Sibley Group is extensively preserved beneath mafic intrusive rocks in more northerly sections of the region. Franklin et al. (1980), Cheadle (1986) and more recently, Rogala (2003) have carried out detailed investigations of the stratigraphy of the Sibley Group. Three major formations, the Pass Lake, Rossport and Kama Hill formations, have been recognized in the literature (Franklin et al. 1980; Cheadle 1986). The characteristics of these formations are briefly described below.

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The Pass Lake Formation consists of the Loon Lake and Fork Bay Members (Cheadle 1986). Its thickness can range from zero to a maximum of 100 m (Rogala 2003). The Loon Lake Member is a thin (<15 m), laterally discontinuous, clast- to matrix-supported conglomerate consisting of clasts of locally derived basement rocks in a brick red sandy matrix with calcareous cement (Franklin et al. 1980; Morey and Ojakangas 1982; Cheadle 1986). Conglomerates of the Loon Lake Member are generally sharply overlain by light coloured sandstones of the Fork Bay Member, although, in places, a gradational fining upwards to pebbly sandstone then sandstone is observed (Cheadle 1986). The Fork Bay Member is comprised mainly of medium-grained sandstones subdivided into 2 main facies (Cheadle 1986). A plane-bedded facies consists of plane to cross-bedded quartz arenites and may contain horizontal laminations, parting lineations, planar cross-beds, oscillation ripples, rare current ripple lamination and rare dewatering features. Thin interbeds of dolomitic mudstone and siltstone may contain desiccation cracks and halite casts. A cross-bedded facies consists of medium- to large-scale cross-bedded arenite occasionally interbedded with 1 m thick planar cross-stratified sandstone units that overlie pebbly scours.

The Rossport Formation may lie disconformably on the Pass Lake Formation (Franklin et al. 1980) or the contact maybe more gradational with the transition marked by a decrease in sandstone beds and an increase in finer grained dolomitic sedimentary rocks (Rogala 2003). The Rossport Formation is divided into 3 members whose total thickness can be up to 100 m (Rogala 2003). The lowermost unit is the Channel Island Member. Cheadle (1986) divided this member into 3 facies: a lower cyclic facies consisting of red mudstone-dolomicrite cycles varying to mudstone–sandstone cycles; an upper mudstone facies consisting of massive friable red mudstones interbedded with relatively thick fine- to medium-

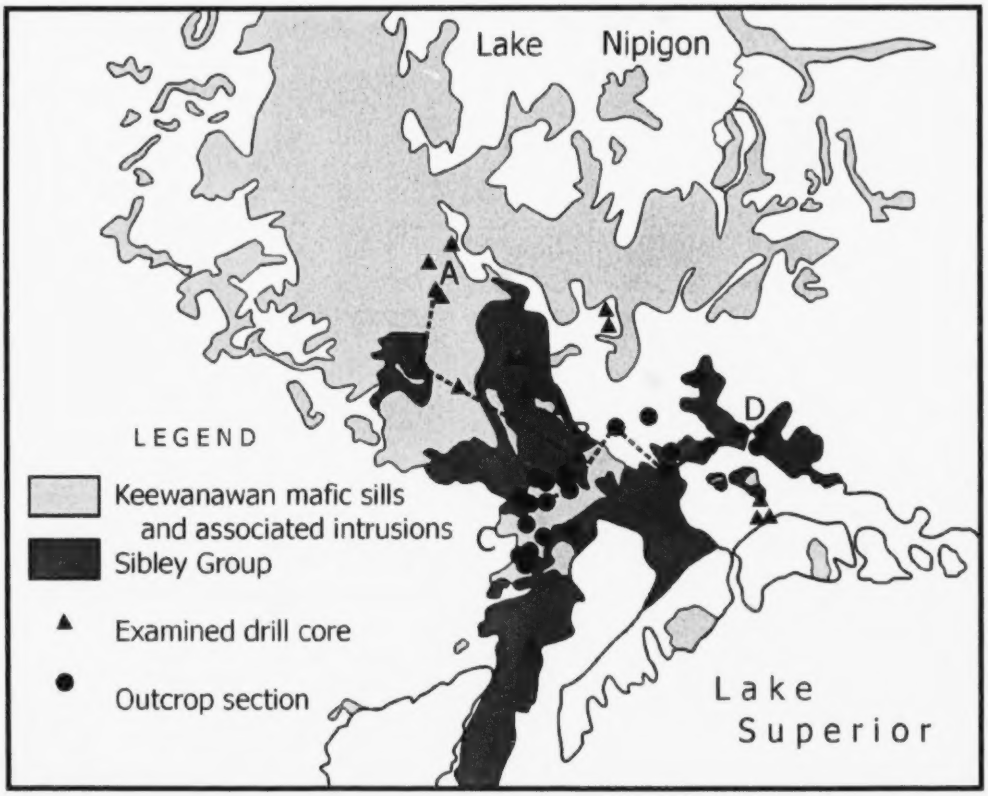

Figure 46.1. Generalized geology south of Lake Nipigon showing the spatial distribution of the Sibley Group and mafic intrusive rocks of the Nipigon Embayment. Letters refer to cross-sections illustrated in Figures 46.2 and 46.3.

grained sandstone bodies; and a locally developed intraformational conglomerate facies. In the cyclic facies, it is often difficult to distinguish dolomicrites from fine-grained sandstones that contain dolomitic cement. Fine-grained dolomitic sandstones are, however, readily distinguished from coarser sandstones associated with the mudstone facies. The sandstones and intraformational conglomerates of the upper portions of the Channel Island Member commonly host a variety of sedimentary structures and synsedimentary deformation features. Individual sandstone units are usually trough cross-stratified and can be as thick as 2 to 3 m. The geometry of these sandstones is often tabular, although, in places, channelized forms occur. Distinctive sand injection features form wedge-shaped sandstone filled cracks into underlying siltstones or can form sandstone dikes and brecciated zones in overlying layers. Interformational conglomerate units contain angular clasts from various underlying lithologies, but dominantly consist of clasts of red siltstone and dolomitic mudstone-sandstone.

The Middlebrun Bay Member overlies the Channel Island Member. This thin (~1 to 2 m) member is stromatolitic and consists of white to grey chert, massive light grey dolomite, crinkly laminated chert-carbonate and laterally linked low amplitude domes of finely laminated chert. Parts of this member are brecciated and it is typically overlain by intraformational conglomerate that represents the base of the Fire Hill Member. In the southeast portions of the Sibley Basin, outcrops of this member are common implying laterally continuity, but, in diamond-drill core, it appears sporadically (Rogala 2003).

The final subdivision of the Rossport Formation is the Fire Hill Member. This member consists primarily of red and buff coloured dolomitic mudstones and siltstones often with intraformational conglomerate found at its base. Reduction spots as well as resistant weathering layers rich in nodular chalcedony are common features of this member (Cheadle 1986). In diamond-drill core, the Fire Hill Member is characterized by red siltstone that contains abundant diagenetic mineral growth including gypsum and/or anhydrite nodules up to 5 cm in diameter. Layers of extremely weathered material containing carbonate nodules are also evident in some cores. Carbonate content decreases to nearly zero at high stratigraphic levels in this member (Franklin et al. 1980).

The Kama Hill Formation represents the highest stratigraphic levels in the Sibley Group that are commonly exposed. On average, its thickness is about 25 m (Rogala 2003). It is primarily composed of purple hematite-rich mudstone and lighter coloured sandy siltstones (Cheadle 1986). In portions of the basin, stromatolites are preserved near the base of this formation and are present at, for example, Stewart Lake (Cheadle 1986; Morey and Ojakangas 1982). Sedimentary structures in thinly interbedded finer grained sections include desiccation cracks and mudchip conglomerates, halite casts and raindrop impressions (Cheadle 1986). Sandier sections contain ripple cross-lamination, normal graded bedding, thin fining-upward cycles and desiccation cracks (Cheadle 1986).

Two additional formations lying above the Kama Hill Formation have been described by Rogala (2003), but are exposed mainly in diamond-drill core from holes drilled in Nipigon Bay and have not been encountered in outcrops on the mainland. Their description in this report is not required as their limited known extent makes them less valuable as a regional tool for Nipigon sill correlation.

LITHOSTRATIGRAPHY OF NIPIGON SILLS AND ASSOCIATED INTRUSIONS

In general, the various lithological elements comprising the Sibley Group are fairly laterally continuous across most of the exposed extent of the Sibley Basin. Even sequences suffering from extreme contact metamorphism can be recognized and placed within the stratigraphy. Given the apparent lack of readily correlative features observed in the Nipigon sills, the stratigraphic relationships between these large intrusive bodies and the Sibley Group provide a valuable tool for assessing regional sill correlations. Important points that this approach will shed light on include

- the number of major and minor sills clearly distinguishable in diamond-drill core and outcrops
- the spatial and stratigraphic distribution of sills
- regional changes in sill thickness
- how effectively sill intrusion is constrained by preferred horizons within the Sibley Group
- possible sill feeder zones

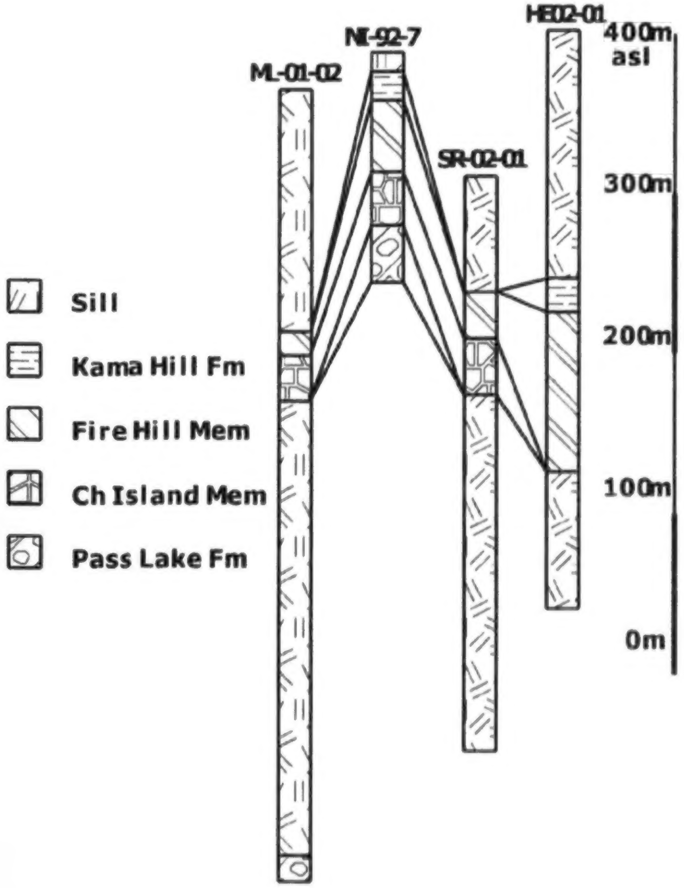

Figure 46.2. Selected generalized stratigraphic sections and possible correlations (Line A–B in Figure 46.1). Note that sections are not drawn to horizontal scale and northwest to southeast is left to right.

- what factors control the current outcrop distribution (i.e., originally how laterally continuous were the sills, to what degree are their distributions controlled by later faulting and erosive removal)

Figures 46.2 and 46.3 display generalized stratigraphic sections derived from a line of diamond-drill holes (*see* Figure 46.1, line A–B) and vertical outcrop profiles (*see* Figure 46.1, line C–D). Figure 46.2 provides a very general picture on a roughly northwest to southeast transect of the stratigraphic relationships between intrusive bodies and the Sibley Group. Though more detailed, spatially extensive three-dimensional correlations are being developed from the data, some basic observations can be made from this section line. A block of Sibley Group rocks separates at least 2 distinct sill complexes, as suggested by Sutcliffe (1986). These are present in, for example, diamond-drill holes ML-01-02 and SR-02-01. In ML-01-02, a thick (200 to 300 m) lower sill complex has a lower contact with the upper Pass Lake Formation or possibly the lowest portions of the Rossport Formation. Distinction is a bit difficult because of contact metamorphic effects. The upper contact of this sill is with the Channel Island Member of the Rossport Formation. A second upper sill complex intrudes the Fire Hill Member at its base, but no upper contact is defined. No upper contacts of this sill were observed to constrain its thickness. In NI-92-7, only a thin sliver of sill is preserved overlying the Kama Hill Formation and may be correlative with the upper sill in ML-01-02. No lower sill is encountered. SR-02-01 and HE02-01 have their igneous and sedimentary rocks arranged in stratigraphic sequences that are similar to ML-01-02. Figure 46.2 represents observed elevations above sea level and shows that if the contacts are correlative then they have likely been disturbed to some degree by post-intrusion faulting.

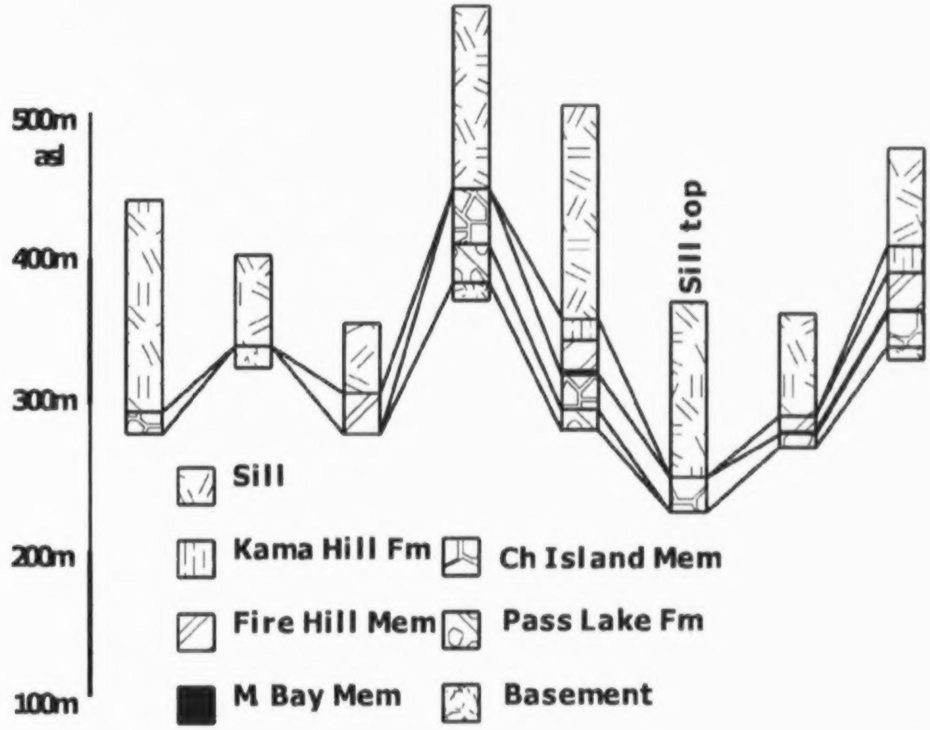

Figure 46.3. Selected outcrop sections west to east (left to right) showing possible correlations (Line C–D in Figure 46.1). Note sections are not drawn to horizontal scale. The approximate position of the Black Sturgeon Fault lies between the 3rd and 4th sections from the left. Abbreviations: Ch Island Mem, Channel Island Member; M Bay Mem, Middlebrun Bay Member.

A section derived from outcrop data along a roughly east-trending transect (*see* Figure 46.1, line C–D) is shown in Figure 46.3. Generally, this section contains a sill of varied thickness that overlies some Sibley Group sedimentary rocks and Archean basement. Photo 46.1 shows typical Sibley-sill contact exposures with moderate contact metamorphic effects in Photo 46.1a and unmetamorphosed Fire Hill Member and Kama Hill Formation in Photo 46.1b. Distinctive sill top features, such as chill margins, are commonly not observed indicating that sill thickness is controlled by erosive removal. The nature of the Sibley Group beneath the sills varies across the section. To the west, portions of the Pass Lake and Lower Rossport formations are commonly intruded and, at times, the sill is in contact with Archean granite. At these more westerly localities, the outcrops may be more correlative with the lower sills observed in diamond-drill core based on this stratigraphic relationship (*see* Figure 46.2). To the east, a sill generally overlies higher levels in the Sibley Group stratigraphy, commonly the Fire Hill Member or the Kama Hill Formation. At Kama Hill, a number of thin sills to gently dipping dikes intrude lower in the Rossport Formation (Photo 46.1c). The geochemistry of these minor intrusions, however, suggests they may be a distinct phase from the Nipigon diabase sills (Hart 2003).

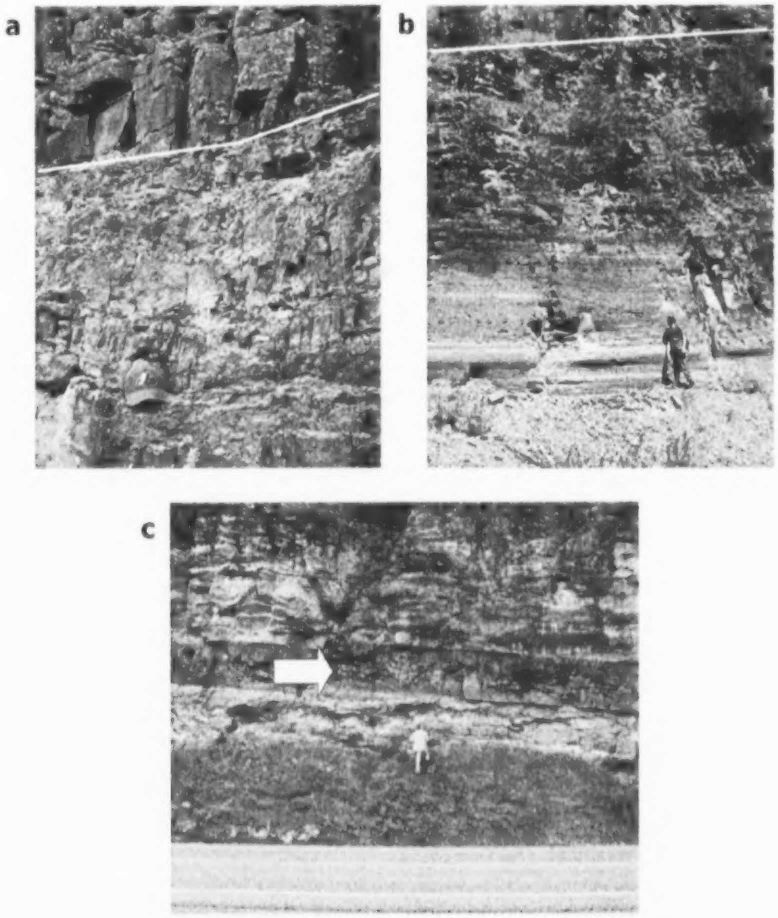

Photo 46.1. a) Contact metamorphosed Sibley Group and overlying diabase sill, east of the town of Nipigon near Highway 17 at Fire Hill (contact highlighted). b) Unmetamorphosed Fire Hill Member and Kama Hill Formation beneath a thin diabase sill, Wolf River Road near the town of Dorion (contact highlighted). c) Gently dipping crosscutting diabase just above Middlebrun Bay Member, east of the town of Nipigon, Highway 17 at Kama Hill (dike location indicated by arrow).

FUTURE WORK

A great deal of data has been generated from study of diamond-drill holes through the diabase–sedimentary succession and the logging of cliff sections in the field. Compilation of this data is very preliminary and continuing work will attempt to address many of the issues raised above. In the near future, a major focus will be to complete three-dimensional models from the extensive amount of diamond-drill core data already collected. This will be supplemented by further field work during 2004 and integrated with data obtained from current Ontario Geological Survey bedrock mapping projects (Hart and MacDonald, this volume) in the LNRGI study area.

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47. Lake Nipigon Region Geoscience Initiative. Preliminary Assessment of Sill Material within the Nipigon Embayment

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[1]Department of Geology, Lakehead University, Thunder Bay, Ontario

INTRODUCTION

This study is being undertaken as part of the Lake Nipigon Region Geoscience Initiative (LNRGI), which is a project funded by both the public and private sector to attract mineral exploration to the Lake Nipigon region (Rayner, Lane and Easton, this volume). The focus of this component of the LNRGI is to provide a regional geochemical and mineralogical analysis of the Nipigon sills and investigate the nature of sill emplacement. The Nipigon sills have been interpreted to be an intrusive basaltic sequence emplaced into the flat-lying, relatively undeformed Mesoproterozoic Sibley Group sediments during the 1.1 Ga Keweenawan rift event centred in the Lake Superior region of the Superior Province (Sutcliffe 1987). The sills cover an area of approximately 10 000 km^2 (Figure 47.1) and represent a minimum volume of 11 000 km^3 (Sutcliffe 1987). Basement rocks in the Lake Nipigon region are primarily Archean with the northern area underlain by rocks of the Wabigoon Subprovince, whereas the southern and central areas are underlain by rocks of the Wabigoon and Quetico subprovinces (*see* Figure 47.1).

RESULTS

Initial field work has focussed on the collection of samples from diamond-drill core and outcrop along the shores of Lake Nipigon. 170 samples were collected from Lake Nipigon (*see* Figure 47.1). An additional 26 samples of diabase sill material were obtained from Kama Hill, approximately 20 km east of the Town of Nipigon on Highway 17. Samples from Kama Hill were taken from the bottom 7 m of the uppermost sill (approximately 60 m remaining thickness) adjacent to the bottom contact with Sibley Group sedimentary rocks. The thin sills lower in the stratigraphy at Kama Hill were also sampled. Diamond-drill core from drilling conducted in 2000 by McVicar Resources and in 2001 by Bitterroot Resources was sampled at 5 m and 2 m intervals, respectively. These cores are presently stored at the off-site diamond-drill core library of the Ministry of Northern Development and Mines in Conmee Township. A total of 530 samples were taken from diamond-drill core. The Bitterroot Resources diamond-drill cores (labelled DDH 1 through DDH 6) were relogged in detail. These cores are from holes that are located in the Shillabeer Lake area approximately 25 km south of Lake Nipigon, and from the McVicar Resources diamond-drill holes located in the Muskrat Lake area, approximately 25 km northeast of the Bitterroot Resources core site. A stratigraphic presentation of 2 diamond-drill holes from Bitterroot Resources (DDH 1 and DDH 6) is illustrated in Figure 47.2. Basic mineralogical interpretation is based on logged drill-hole cross-sections.

Summary of Field Work and Other Activities 2003,
Ontario Geological Survey, Open File Report 6120, p.47-1 to 47-5.

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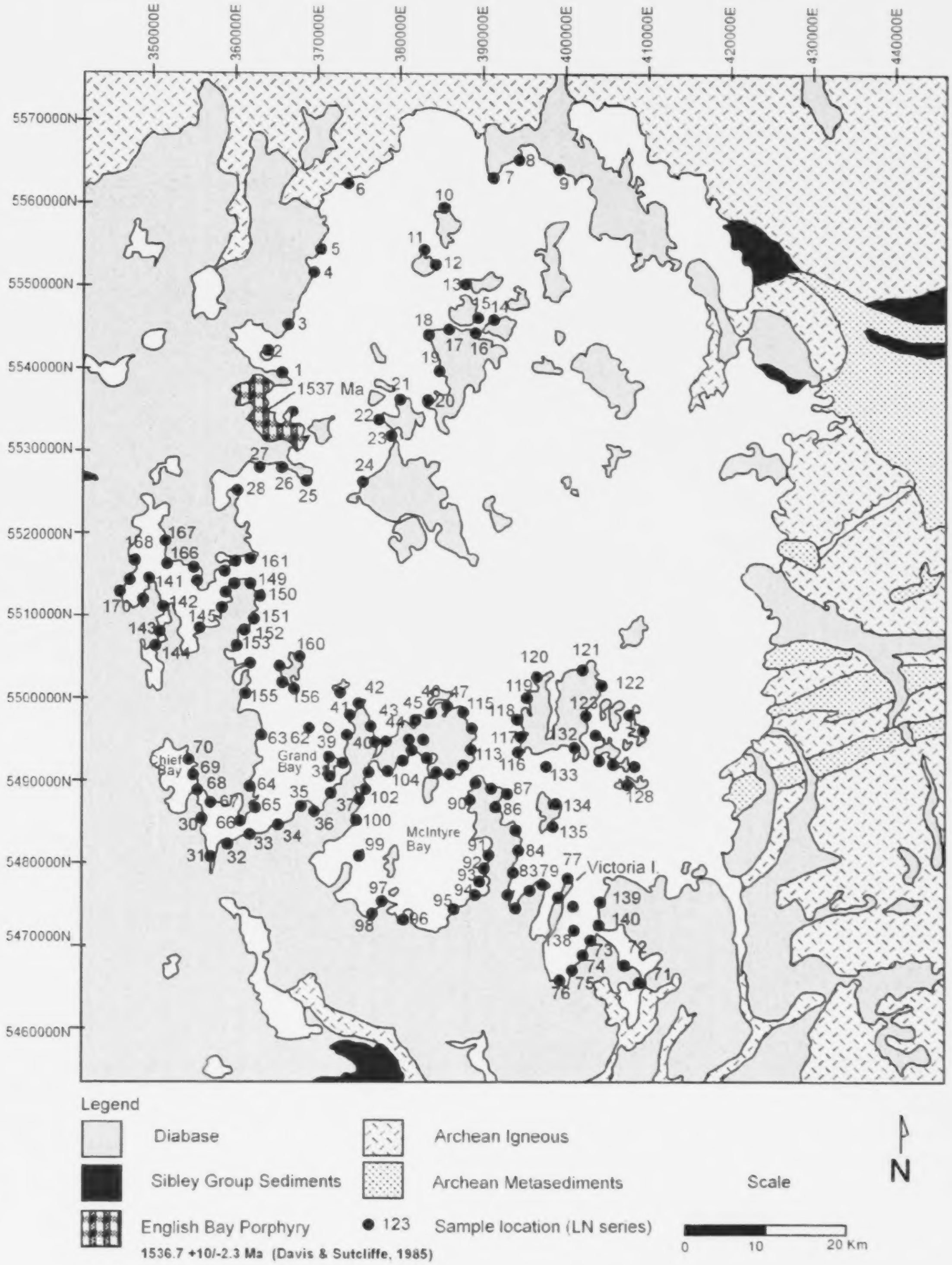
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5520000N
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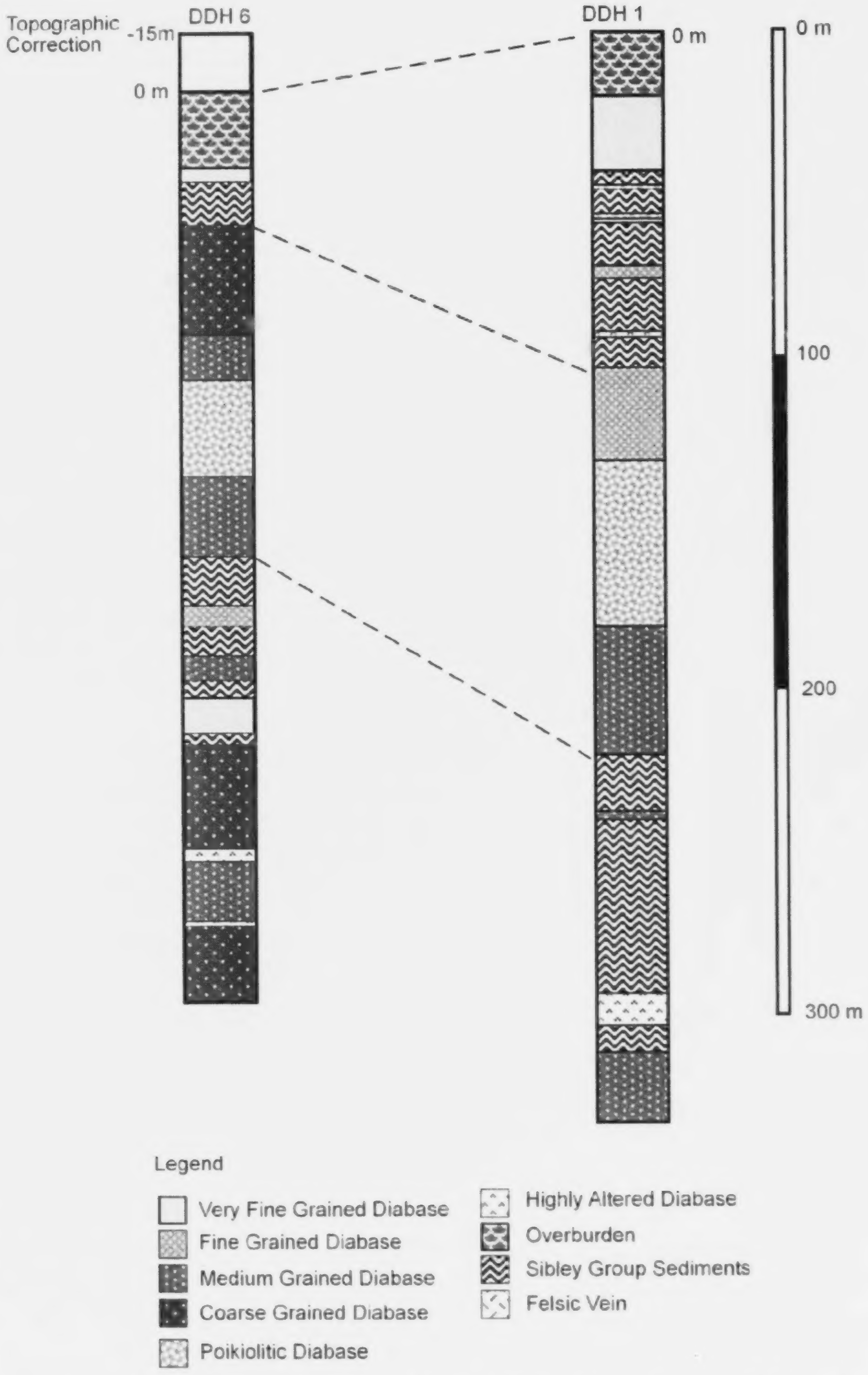
5480000N
5470000N
5460000N
1537 Ma
Chief Bay
Grand Bay
McIntyre Bay
Victoria I.
Legend
Diabase
Sibley Group Sediments
English Bay Porphyry
1536.7 +10/-2.3 Ma (Davis & Sutcliffe, 1985)
Archean Igneous
Archean Metasediments
● 123 Sample location (LN series)
Scale
0
10
20 Km
N

Figure 47.1. Lake Nipigon regional geology and sample locations (*modified after* Sutcliffe 1986).


Topographic Correction
-15m
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DDH 6
DDH 1
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0 m
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200
300 m
Legend
Very Fine Grained Diabase
Fine Grained Diabase
Medium Grained Diabase
Coarse Grained Diabase
Poikiolitic Diabase
Highly Altered Diabase
Overburden
Sibley Group Sediments
Felsic Vein

Figure 47.2. Diamond-drill core log comparison from DDH 1 and DDH 6, Bitterroot Resources, Shillabeer Lake area.

DISCUSSION

Preliminary data from diamond-drill core logs have revealed variations in textural relationships and mineral concentrations. The absence of clear chill margins combined with layer-like changes in grain size, particularly within what appear to be single sills in diamond-drill core, may be evidence of several pulses of magma being injected within a short period of time. This mineralogical and textural zoning is particularly evident in the McVicar Resources (ML-series) diamond-drill cores. A very coarse to pegmatitic zone up to 30 m thick can be found in core from all 3 ML-series diamond-drill holes. The pegmatitic unit retains a reasonably constant thickness. The lower contact with an approximately 20 m thick, magnetite-rich unit is clear, with a gradational decrease in grain size over 10 to 20 cm.

Stratigraphic correlation between the Bitterroot Resources (DDH-series) diamond-drill holes based on core-logging is more difficult. Figure 47.2 depicts holes DDH 1 (UTM: NAD 27, Zone 16, 376365E, 5437493N) and DDH 6 (UTM: NAD 27, Zone 16, 376663E, 5437496N) separated by 300 m along an east-west axis and approximately 15 m vertically. The distribution of sedimentary units and the character of the diabase within these holes cannot be easily stratigraphically correlated despite the geographic proximity of the diamond-drill holes. DDH 1 was collared in Sibley Group sedimentary rocks with multiple thin beds of highly metamorphosed sedimentary rocks in the first 100 m of the hole. A significant thickness of Sibley Group sediment appears at 200 m down the hole and extends to nearly 300 m. Diabase injected into the Sibley Group near the top of the hole is very fine grained to aphanitic, and lighter coloured, which possibly indicates contamination by assimilated Sibley Group sedimentary rocks. Similar diabase–Sibley Group contacts to those observed in DDH 1 are present in DDH 6. However, the Sibley Group sedimentary rocks were intersected between 130 and 170 m in DDH 6 with no other units of Sibley Group sedimentary rocks in the remainder of the diamond-drill hole. The remaining 4 Bitterroot Resources diamond-drill holes (DDH 2 through DDH 5) are shallower (<170 m in total length) and contain multiple units of highly metamorphosed Sibley Group sedimentary rocks and very fine-grained to aphanitic diabase. The contact angle between diabase and Sibley Group sedimentary rocks remains horizontal with respect to core angle in all of Bitterroot Resources' diamond-drill holes. Changes in grain size within the diabase in these holes may be consistent with multiple pulses of magma injection within what appears to be a single thick sill. The lack of stratigraphic correlation of rock types between the 2 diamond-drill holes (*see* Figure 47.2) suggests that the diabase units may not be separate sills, but rather apophyses from a single, thicker sill. The layers of sedimentary rocks in these diamond-drill holes may be preserved remnants between the sills or possibly blocks of Sibley Group sedimentary rocks, which have detached from the roof of a greater than 200 m thick sill. The former explanation is preferred based on the uniformity of contact angles within all diamond-drill drill holes and the fact that all the holes were drilled at a 90°.

Samples taken from outcrops along the Lake Nipigon shoreline are primarily medium-grained diabase. Samples from the northern portion of the lake are typically more olivine rich than samples from the southern lakeshore. Peridotite boulders were found on the northeast shore of McIntyre Bay, near sample LN90 (UTM: NAD 27, Zone 16, 388563E, 5482342N), but no source outcrop was located. Diabase sill–Sibley Group contacts were rare and observed only in the southern portion of Lake Nipigon on the eastern shore of Chief Bay near sample LN167 (UTM: NAD 27, Zone 16, 352634E, 5519762N) and the southeast shore of Grand Bay near sample LN146 (UTM: NAD 27, Zone 16, 350481E, 5512813N). The Chief Bay contact contained a layer up to 40 cm thick, of which the top 10 cm was glassy followed by up to 30 cm of vesicle-rich rock. This glass and vesicle layering was also observed on a shoal in the southwest portion of McIntyre Bay near sample LN99 (UTM: NAD 27, Zone 16, 374329E, 5486794N). A possible layered diabase sill was observed on a small island located approximately 500 m east of the north tip of Victoria Island in South Bay of Lake Nipigon.

An example of sill variation in outcrop can be observed at Kama Hill, an extensive sill–Sibley Group section located approximately 25 km east of the Town of Nipigon on Highway 17. Photo 47.1 shows 2 diabase sills intruding the Channel Island Member of the Rossport Formation. The lower sill is discontinuous and terminates toward the west end of the roadcut. This termination of thin sills present within the Sibley Group sedimentary rocks is common and illustrates why correlation of sills across even short distances between diamond-drill holes is difficult.

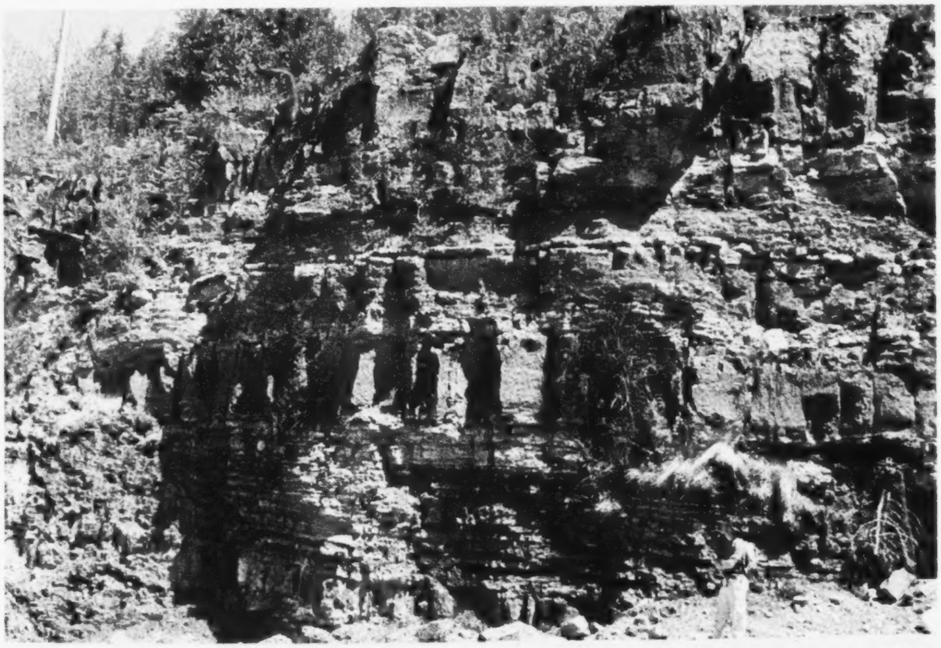

Photo 47.1. Discontinuous sill at Kama Hill (note: senior author for scale). See text for additional details.

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48. Lake Nipigon Region Geoscience Initiative. Petrology and Mineral Chemistry of the Seagull Intrusion

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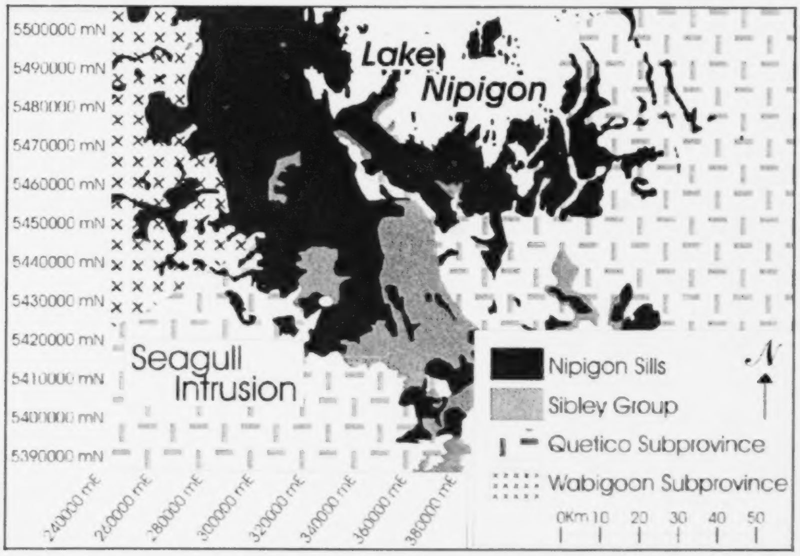
INTRODUCTION

Exploration for platinum group element (PGE) mineralization around Lake Nipigon started in the 1980s with the identification of mafic to ultramafic intrusions as favourable targets for magmatic mineralization. Work commenced on the Seagull intrusion (Figure 48.1) in 1987 by Platinum Exploration Canada Limited, who conducted a geological mapping and sampling program, very low frequency electromagnetic (VLF–EM) and ground total field magnetic surveys over the intrusion. Exploration targets were not identified and the ground lapsed. Cominco Limited staked and carried out an aeromagnetic survey and ground gravity profiles over the area in 1992 but allowed the claims to lapse. An area of magnetic sand found above the intrusion was then staked by R. Fairservice and optioned to Avalon Ventures Ltd. in 1997 with additional claim staking in the surrounding area. In 1999, East West Resources Corporation and Canadian Golden Dragon formed a joint venture with Avalon Ventures Limited (Pettigrew 2002). Diamond drilling conducted from 1998 to 2000 identified a number of mineralized zones throughout the intrusion (Rees 2000; Osmani and Rees 1998a, 1998b). This current work is funded in part by East West Resources Corporation and the National Research Council of Canada as part of the Industrial Research Assistance Program. The objective is to understand the formational history of the Seagull intrusion in hopes of identifying other favourable targets for PGE exploration.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320000 mE
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Lake Nipigon
Seagull Intrusion
Nipigon Sills
Sibley Group
Quetico Subprovince
Wabigoon Subprovince
N
0Km 10 20 30 40 50

Figure 48.1. Regional geology of southern Lake Nipigon, showing location of the Seagull intrusion.

Summary of Field Work and Other Activities 2003,
Ontario Geological Survey, Open File Report 6120, p.48-1 to 48-5.

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Field work commenced in September of 2002, and focussed on sampling of diamond-drill core, which would give the best representation of the intrusion, given the poor surface exposure. Diamond-drill core samples were selected based on original drill logs to reflect all lithologies present in the core. Additional samples were collected when thick homogenous units were encountered in the core. Further sampling of diamond-drill core was undertaken in January, 2002. Surface samples from the intrusion were collected in July, 2003. Petrographic analyses of 80 samples from diamond-drill core were undertaken to determine mineralogy, textures, mineralization and alteration. Additional analyses of 41 samples have been undertaken using the scanning electron microscope–energy dispersive spectrometry (SEM-EDS) at Lakehead University for semi-quantitative and fully quantitative analysis of olivine, oxide minerals, pyroxene, amphiboles, feldspars, platinum group minerals and sulphides.

ROCK TYPES

Rock units observed in the Seagull intrusion range from mafic to ultramafic with few sharp contacts observed in diamond-drill core. Most contacts are gradational with a decrease in one mineral phase and simultaneous increase of another. Based on the petrographic analyses undertaken to date, 5 rock types are recognized: dunite, lherzolite, olivine websterite, olivine hornblende pyroxenite, and a Nipigon sill of olivine gabbronorite composition. The Nipigon sill is interpreted to postdate the Seagull intrusion, based on crosscutting relationships and chill margins observed in diamond-drill holes WM00-01 and WM98-05 (Figure 48.2).

The dunite phase of the intrusion is found in the upper 450 to 500 m of the intrusion (*see* Figure 48.2). The dunite is characterized by approximately 90% or more of olivine, with the remaining 10% consisting of pyroxene, dominantly found as oikocrysts enclosing olivine chadacrysts, and very rarely as discrete crystals. Crystal size is varied throughout the intrusion, ranging from fine to medium grained, but is generally consistent within discrete horizons where rare phenocrysts of coarse-grained olivine occur. Oxide mineral phases are also present and are typically found as inclusions in the olivine, surrounding the olivine and as alteration minerals. The dunite has undergone varied alteration from complete replacement of olivine near its top to only minor alteration at depth. Pervasive hematization is also common.

The lherzolite phase is found throughout the intrusion in zones that are gradational with the dunites and located near the base of the intrusion below the dunite (*see* Figure 48.2). The lherzolite is characterized by olivine abundance between 40 and 90% with the remaining mineralogy consisting of pyroxene and mica. Pyroxene always forms as oikocrysts enclosing olivine crystals. Oxide minerals are found throughout the lherzolite in varying abundance (up to 2%). The lherzolite generally shows less alteration than the dunite.

The olivine websterite is found dominantly at the base of the intrusion within 100 m of the basal contact (*see* Figure 48.2) and is characterized by olivine abundance between 10 and 40%. Remaining mineralogy consists of pyroxene (50 to 60%), amphibole (0 to 5%), mica (2 to 5%), trace feldspar, and various oxide minerals. Pyroxene occurs as oikocrysts and subhedral crystals. Mica and amphiboles are found as intergranular crystals between pyroxene. Alteration of this unit is moderate with many of minerals showing partial replacement by chlorite.

The olivine hornblende pyroxenite is characterized by pyroxene content between 50 and 90% and is found only at the base of the intrusion in contact with basement gneiss (*see* Figure 48.2). Pyroxene grains exhibit anhedral to subhedral forms with varied crystal sizes. Amphibole abundance is varied (10 to 50%). Amphibole is interpreted as an alteration product rather than the result of primary crystallization. The olivine hornblende pyroxenite contains varied amounts of olivine but generally less than 5%. Biotite (up to 10%) occurs throughout this unit as intergranular crystals to pyroxene. Trace feldspar is also present.

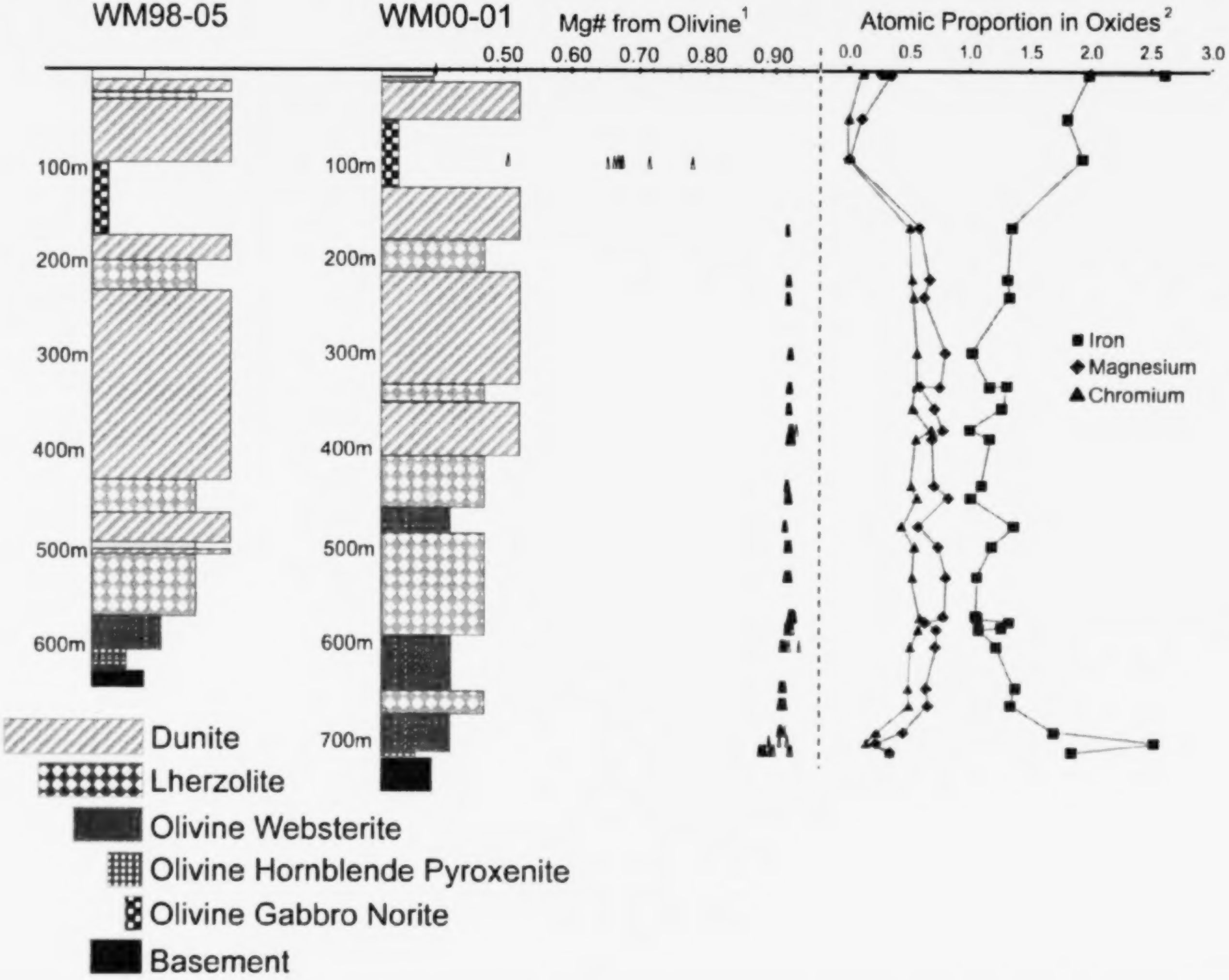

Figure 48.2. Lithostratigraphic columns for drill holes WM98-05 and WM00-01 based on thin-section petrology. Mg# from olivine, and molecular proportion in oxide minerals from WM00-01, derived from SEM-EDS full quantitative analysis. [1] Mg# = Mg(at)/[(Mg(at)/Fe(at)]; [2]atomic proportion based on 3 metal ions.

The olivine gabbronorite (Nipigon sill) is found in the cores of all the diamond-drill holes and maintains a constant thickness and elevation in the intrusion (*see* Figure 48.2). The gabbronorite is characterized by 30 to 50% coarse- grained pyroxene oikocrysts, 30 to 50% plagioclase feldspar, varied amounts of olivine (0 to 10%), and trace amphibole. Oxide minerals are present and dominantly consist of ilmenite. Alteration is minor and localized along fractures consisting of chlorite, muscovite, albite and illite.

Mineral Chemistry

Mineral chemistry analyses were carried out at Lakehead University using a Jeol 5900 scanning electron microscope. Thin sections were selected based on spatial distribution through diamond-drill hole WM00-01 to represent all rock types observed in the initial logging of the hole (Rees 2000; Osmani and Rees 1998a, 1998b) and further screened to select those samples exhibiting the least alteration and replacement. Analyses were carried out on olivine, oxide minerals, sulphide minerals and platinum group minerals to investigate variations in mineral chemistry associated with stratigraphic position in the intrusion. Analyses were also carried out on pyroxene, feldspars, amphiboles and micas when encountered.

Olivine

Olivine compositions are broadly constant throughout the intrusion (*see* Figure 48.2) with an average composition of forsterite$_{90\text{-}91}$ (excluding the Nipigon sill). Within the intrusion, there are areas where the olivine composition varies (*see* Figure 48.2). The first variation occurs at the base of the intrusion where there is a scatter toward both iron and magnesium enrichment. The second and third zones of olivine variation occur at 571-573 m and 376 m where the olivine composition becomes more primitive to forsterite$_{92\text{-}93}$. Sulphide mineralization occurs around both of these zones (572 to 582 m and 375 to 377 m) (Rees 2000). The olivine grains in the Nipigon sill are enriched in iron relative to the Seagull intrusion, with an average composition of forsterite$_{68}$.

OXIDE MINERALS

Oxide mineral compositions throughout the intrusion show a wide range of variation through substitution of iron, chromium, magnesium and aluminum. There does appear to be a general increase in Fe near the base and at the top of the intrusion, with a corresponding increase in aluminum, chromium and magnesium in the centre section of the intrusion. There are sharp fluctuations in the atomic proportions of iron, magnesium and chromium (*see* Figure 48.2) at stratigraphic levels, which correlate with the olivine variations and zones of sulphide mineralization.

SULPHIDE AND PLATINUM GROUP MINERALS

Mineralized zones occur throughout the intrusion in the form of disseminated sulphide minerals (Kissin, this volume; Pettigrew 2002; Rees 2000; Osmani and Rees 1998a, 1998b). The dominant sulphide phase is bravolite with minor amounts of sphalerite, chalcopyrite, pyrite, native copper and silver. Platinum group minerals have been recognized in 3 mineralized thin sections. They are always found adjacent to sulphide minerals and are interpreted to be magmatic in origin. To date stibiopalladinite, keithconnite, sperrylite and kotulskite have been identified.

DISCUSSION

Work to date on the Seagull intrusion during this study has focussed on rocks in diamond-drill hole WM00-01. The mineralogical work done on the olivine and oxide minerals and the whole rock data would indicate that the Seagull intrusion is very homogenous. Minor changes in olivine composition to a more primitive form associated with zones of sulphide mineralization may indicate the influx of less evolved magma into the chamber. This less evolved magma, along with containing more magnesium, may also have carried platinum group elements, now represented by the disseminated sulphide minerals and platinum group minerals found at these horizons.

FUTURE WORK

Continued mineral analysis of olivine, oxide minerals and pyroxene will be undertaken in diamond-drill holes adjacent to WM00-01 with the use of the SEM–EDS to identify stratigraphic changes in mineral compositions and their relationships to the mineralized zones in the intrusion. Additional whole rock analysis, trace element analysis (rare earth elements) and radiogenic isotope studies will further aid and supplement the existing database of whole rock samples analyzed using inductively coupled plasma atomic emission spectroscopy (ICP–AES). These will define the magmatic history of the intrusion and its association with the Nipigon sills, if any.

ACKNOWLEDGMENTS

We thank Bob Middleton and East West Resources Corporation for their support and access to the drill core and property.

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49. Project Unit 03-023. Surficial Geochemistry and Mapping Case Studies Project, Lake Nipigon Region Geoscience Initiative

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INTRODUCTION

The surficial geochemistry and mapping case studies project is part of the Lake Nipigon Region Geoscience Initiative (LNRGI) administered by the Ontario Prospectors Association (OPA). The goal of the LNRGI is to stimulate mineral exploration for platinum group element (PGE) deposits, specifically within the Lake Nipigon Embayment, by sponsoring geoscience studies in new and proven technologies and methods. One of the ways the objective of LNRGI will be achieved is through completion of the surficial geochemistry and mapping project. This project focusses on the acquisition, interpretation and dissemination of multi-media geochemical data and surficial and/or Quaternary map products derived from case studies around known PGE mineralization and PGE anomalous lake sediment sites. The case study areas selected by the LNRGI scientific committee are shown in Figure 49.1. The Lac des Iles and Tib Lake study areas cover known PGE mineralization in bedrock, while the Cheeseman Lake, Right Angle–Muskrat–Circle lakes and Tarrison Lake study areas cover significant PGE lake sediment anomalies.

The data and interpretations resulting from the current project will benefit all explorationists in the province, particularly with regard to helping better understand the exploration significance of surficial geochemical anomalies over a variety of surficial landscape conditions. In particular, 3 objectives have been identified by the LNRGI Science Advisory Committee as goals of this study, namely to

1. evaluate, develop and recommend cost-effective PGE exploration sampling strategies and analytical techniques in surficial media
2. determine the extent of both chemical and glacial (physical) dispersion from known PGE mineralization and/or gabbro by sampling and analyzing drainage (including waters) and glacially deposited materials
3. determine the source(s) of anomalous levels of PGEs in lake sediment and develop strategies and/or methodologies for effective follow-up

In order to achieve these objectives, the following tasks have been identified as the core requirements of this project:

1. surficial Quaternary mapping to determine the distribution of surficial glacial deposits and their associated ice flow or melt water flow directions, specifically in the vicinity of known PGE mineralization and/or lake sediment PGE anomalies

Summary of Field Work and Other Activities 2003,
Ontario Geological Survey, Open File Report 6120, p.49-1 to 49-8.

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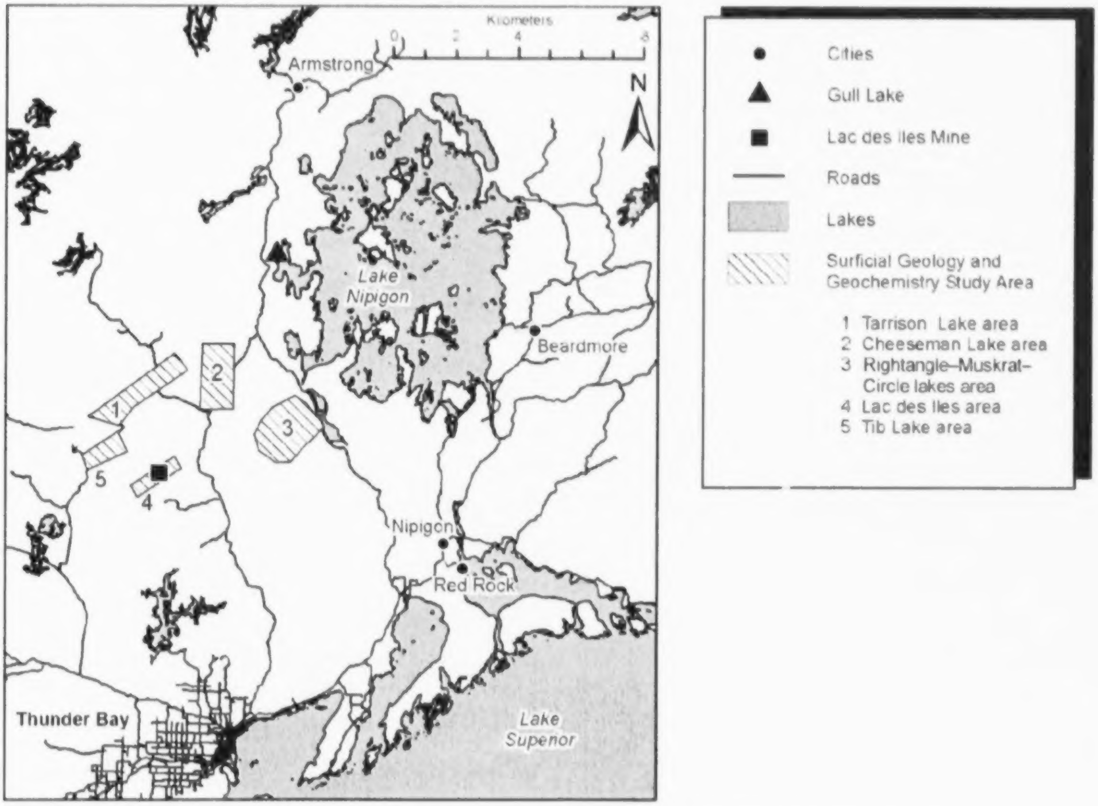
2. collection and analysis of water and organic substrates within the drainage system to identify and geochemically characterize the hydromorphic inputs likely to affect lake sediment composition
3. collection and analysis of inorganic stream sediments to identify and geochemically characterize the mechanical inputs likely to affect lake sediment composition
4. collection and analysis of subglacial till deposits and glaciofluvial sediments to geochemically characterize and determine if these materials are sources for PGE lake sediment anomalies
5. collection and analysis of rock samples to determine and geochemically characterize possible bedrock sources for PGE lake sediment anomalies
6. compilation and dissemination of this information in the form of hard-copy and digital reports that outline the various geochemical dispersion case histories

Field work on the case study areas was carried out between June 23 and October 1, 2003. For the most part, field work was based out of the Lac des Iles mine site and, for the last 3 weeks, from the Ministry of Natural Resources base at Rinker Lake. Access to the case study areas was accomplished by a combination of 4x4 trucks, all-terrain vehicles (ATVs), boats and on foot. Approximately 5 hours of helicopter time was used to obtain infill and verification lake sediment and water samples from 4 of the case study areas. The final project report is expected to be completed and submitted to the LNRGI Science Advisory Committee by March 31, 2004.


Kilometers
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Armstrong
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Beardmore
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3
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5
Nipigon
Red Rock
Thunder Bay
Lake Superior
Cities
Gull Lake
Lac des Iles Mine
Roads
Lakes
Surficial Geology and Geochemistry Study Area
1 Tarrison Lake area
2 Cheeseman Lake area
3 Rightangle–Muskrat–Circle lakes area
4 Lac des Iles area
5 Tib Lake area

Figure 49.1. Location of case study areas, LNRGI surficial geochemistry and mapping project.

REGIONAL BEDROCK GEOLOGY

Bedrock mapping in the area was completed by Milne (1964), Pye (1965, 1968), Kaye (1967a, 1967b, 1969) and Coates (1969, 1972). Sage (1998) re-evaluated this early work. Sutcliffe and Sweeny (1986), Smith and Sutcliffe (1987) and Sutcliffe and Smith (1988) concentrated mapping efforts on the Lac des Iles and Tib Lake intrusions. Hart, MacDonald and Lepine (2001a, 2001b) have completed the most recent mapping in the Lac des Iles and Garden Lake areas. From these sources it is apparent that the study area consists of six major rock suites, namely:

1. Quetico Subprovince metasedimentary rocks, paragneiss, migmatite and granite
2. inter-greenstone belt granodiorite to granite intrusions
3. supracrustal ultramafic to intermediate rocks, with minor felsic rocks, of the Bo Lake–Heaven Lake and Lac des Iles greenstone belts
4. the "Ring of Fire" mafic to ultramafic intrusions, including the Lac des Iles and Tib Lake intrusions
5. Nipigon diabase, in the form of sills and dikes, is the dominant rock type in the Nipigon Embayment
6. Sibley Group sedimentary rocks that crop out or subcrop mostly within the southern part of the Nipigon Embayment

Much attention has been given to the PGE potential of the ultramafic intrusions in the study area. Pye (1965) was the first to map the intrusive bodies, followed by a more detailed study by Sage (1998). Extensive exploration by Boston Bay Mines–Madeleine Mines Ltd (now North American Palladium) led to the development of the Lac des Iles Mine, the only producing primary platinum-palladium mine in Canada. The Lac des Iles complex consists of a southern ultramafic centre, containing a wehrlite core, surrounded by websterite and gabbronorite cumulates. The northern ultramafic centre contains several cycles consisting of basal dunite to wehrlite cumulate rocks, overlain by clinopyroxenite and websterite rocks, and localized gabbronorite (Brugmann and Naldrett 1988).

Nipigon diabase sills in the area are monotonous in textural appearance and are difficult to distinguish by visual appearance in the field from other discrete mafic to ultramafic bodies (T.R. Hart, OGS, personal communication, 2003). Several mafic to ultramafic intrusions have been identified within the Nipigon Embayment and are being explored by several mineral exploration companies for PGEs. These include the Disraeli and Seagull intrusions, and an intrusive complex underlying a diabase sill in the Muskrat Lake–Circle Lake area, straddling the trace of the Quetico Fault (Dyer and Russell 2002).

REGIONAL QUATERNARY GEOLOGY

The Quaternary geology of the area south and west of Lake Nipigon has been investigated at only a regional scale despite its importance to the overall understanding of the glacial history of Ontario and, in particular, to mineral exploration using unconsolidated sediments (drift exploration). Regional maps at various scales that cover the area include Zoltai (1965a), Sado and Carswell (1987) and Barnett, Henry and Babuin (1991). Zoltai (1965b) described and discussed the formation of some of the major landforms and deposits of the Quetico–Nipigon area. Mollard and Mollard (1981a, 1981b, 1981c, 1983) undertook a terrain analysis of the study area and produced maps of some of the major landforms and material types that occur there. Several theses and papers have been written on significant aspects or features of Quaternary age from within the area of interest (Lemoine 1989; Schlosser 1983; Teller and Thorliefson 1983, 1987; Teller and Mahnic 1987).

Regional concepts of the glacial history southwest of Lake Nipigon have been summarized by Zoltai (1965a, 1965b), Elson (1967), Prest (1970), Dredge and Cowan (1989) and Barnett (1991). There is very little agreement as to the details of the sequence and timing of events. The deposits in the area probably represent ice movement during the Michigan Subepisode (Late Wisconsinan), however, they may reflect ice cover during the entire Wisconsin Episode or approximately the last 100 000 years. In general, the Laurentide Ice Sheet flowed southwestward across the study area during its maximum extent about 20 000 years ago. During deglaciation and possibly during initial ice movement into the area, ice-flow direction was controlled on a regional scale by topography. During these times, ice flow followed broad topographic lows, especially the Great Lakes basins and most likely Lake Nipigon, producing lobate ice margins that could have possibly behaved somewhat independently.

METHODOLOGY

Surficial Mapping

The initial steps toward deciphering the Quaternary history of each case study area involved the identification of major landforms using digital elevation models (DEMs), Landsat ETM imagery and the extensive use and interpretation of 1:50 000 and 1:20 000 scale airphotos.

Field mapping techniques included the examination of geological material and their characteristics within existing natural and man-made exposures, soil probe cores, auger cuttings and test pits. Bedrock surfaces were examined for evidence of direction(s) of ice and meltwater movement and the conditions at the base of the glacier during glacial overriding. Observations were recorded in a digital database that is linked to a geo-referenced point coverage of observation site locations. Observations at each site included type of exposure, topography, position on slope, slope, and interpreted landform. Information on the materials exposed included thickness, colour, grain size, stratification, structure and upper and lower contact characteristics. In addition, soil horizon characteristics and sample locations were recorded. Materials deemed "representative" of a certain map unit were sampled, to be later analyzed for more detailed information on physical and chemical properties.

Digital maps of the Quaternary geology for each case study area, a brief report discussing the glacial history, material properties and their implications to mineral exploration studies using glacial and postglacial sediments are expected products of the current work.

Sampling Methodologies

INTRODUCTION

Well-established methods and protocols for all surficial media sampling was employed during this project. Precise global positioning system (GPS) co-ordinates were collected at all sample sites utilizing Trimble GeoXM™ and/or GeoExplorer® 3 receivers. All GPS co-ordinates were collected and saved in North American Datum 1983 (NAD 83), Zone 16. Daily downloading to a laptop computer and periodic backup of data, by recording to CD-ROM, ensured data safety and integrity. Sample site locations were also plotted on airphotos and/or 1:50 000 scale topographic maps in the field at the time of collection. Field duplicates for all sample media were collected at a rate of approximately 1 sample in 20.

GLACIAL DEPOSITS

In general, glacial materials were collected along lines perpendicular to the dominant flow (ice or water) direction. The position of the lines and samples along the lines were selected to obtain representative samples from all major mappable glacial sediment facies. The distribution of sample sites were selected so as to determine whether lateral variations in trace element content exist orthogonal to the dominant direction of ice and/or meltwater flow. As appropriate, humus, "B" and "C" soil horizon samples were collected. For samples destined for fine-fraction geochemistry, approximately 1 to 2 kg of material was collected in breathable polypropylene bags and air dried. Modern alluvium and till samples collected for heavy mineral concentrate (HMC) were passed through a 5 mm screen and placed in heavy gauge plastic bags. Approximately 15 kg of material was collected for each sample destined for HMC processing.

Over the course of the summer, a total of 194 sites were sampled (either cut sections or dug test pits) resulting in the collection of 194 "C" horizon tills, 168 "B" horizon soils and 128 humus samples. In addition, 25 samples for HMC processing were collected, most consisting of modern alluvium collected from rivers.

INORGANIC AND ORGANIC DRAINAGE SUBSTRATES

Approximately 1 to 2 kg of inorganic stream sediment was collected from streams bottomed by coarse clastic sediment for fine-fraction geochemistry. For such sample sites, preference was given to low energy sites where silt-sized material was available for sampling. This material was placed in breathable fabric bags and air dried in the field prior to shipment to the laboratory. Relevant sample description information included the type of material, grain size distribution (clay, silt, sand, gravel), composition (percent mafic grains) and colour. Modern alluvium samples for indicator mineral analysis were approximately 15 kg in size.

At each river or creek site where organic materials were an available substrate, well-decomposed organic materials in contact with the water were collected to help characterize hydromorphic inputs into the case study lakes. Sample sites included organic mud on the stream bottom or organic bank material from A-horizon soil in contact with stream water.

Where present, well-decomposed peat from a depth of at least 1 m was obtained from bogs located at the headwaters of streams. This material was placed in breathable polypropylene bags and transported in Whirl-Pak® plastic bags to avoid leakage and cross-contamination. Relevant sample description information included the type of sample, sample depth, texture and colour.

A total of 107 river or creek sites were visited resulting in the collection of 69 inorganic and 60 organic sediment samples. In addition, 58 peat samples were obtained from either bogs at the headwaters of streams or from bogs located on the fringe of lakes.

WATER

Water samples were collected in conjunction with lake sediment samples following standard OGS methodology. Stream and bog waters were collected from the centre of stream channels and/or the centre of drainage pathways within bogs. Detailed sampling around lakes with anomalous sediment geochemistry involved traversing the entire shoreline area to find all possible drainage inputs into the lake (e.g., creeks, springs). Preference was given to sites exhibiting visible surface water flow. Where appropriate, water from peat bogs was sampled by first digging a sump, allowing it to fill with water, allowing suspended material to settle, and then taking the sample. Alternatively, a 0.010 inch (0.25 mm) slot piezometer pipe was pushed to a depth of approximately 1 to 1.2 m (3 to 4 feet) and water was extracted using a polyethylene hose and Teflon® foot valve. Stagnant water at the edge of bogs or drainage valleys was avoided. Water sampling was suspended during heavy rainfall and for at least one full day following the cessation of rainfall. Lake, stream, bog, spring and ground waters were collected in translucent 250 mL high-density screw-cap polyethylene bottles (HDPE). Only new bottles were utilized (no reuse of bottles). A total of 225 water samples were collected during the course of the field season, including 48 from bogs (shallow groundwater), 20 groundwater samples (obtained by piezometers from at least 1 m depth) and 20 from natural springs. Filtration by syringe and Millipore Sterivex™ filters was done within minutes of sample collection, followed by acidification with ultrapure nitric acid to 0.6%. A separate aliquot for gold and PGE analysis was filtered, but not acidified.

Most waters were tested *in situ* for pH, temperature, electrical conductivity and oxidation–reduction potential (ORP) with portable handheld meters. Waters obtained by piezometer were tested within minutes of extraction. The performance of all meters was checked and recorded each night. The pH meters were calibrated daily.

LAKE SEDIMENT

Standard OGS lake sediment sampling methodologies were employed for this project (Dyer and Russell 2002). Most sample sites were accessed through a combination of helicopter and boat use. Some lake waters were collected from the shoreline during traverses within drainage catchments. A total of 45 lakes were visited resulting in the collection of 30 lake sediments and 45 lake waters.

ROCK

Rocks within each case study drainage catchment were sampled. This included diabase, gabbro and any other mineralized or non-mineralized mafic rocks considered prospective for PGE mineralization. Sample sites included both outcrop and glacially transported boulders. Approximately 1 kg of representative chips were collected from different parts of each outcrop or boulder, placed in plastic bags and securely sealed prior to shipping to the laboratory. Relevant sample description information included sample type (bedrock, boulder), rock type, texture, grain size distribution (percent fine, medium, coarse), sulphide content, degree of magnetism, and colour. A total of 91 rock samples were collected during the field season.

Sample Preparation and Analytical Methods

All samples will be dried before being shipped to an external laboratory for preparation and analysis. Analysis of inorganic and organic surficial media will include aqua regia digestion followed by inductively coupled plasma mass spectrometry–optical emission spectroscopy (ICP–MS–OES) for most major, minor and trace elements and fire assay–inductively coupled plasma mass spectrometry (FA–ICP–MS) for gold and PGEs. Waters will be analyzed by ICP–MS–OES for a suite of over 50 elements. For reliable gold and PGE data and in order to achieve the required detection limits of this project, the waters will likely have to undergo treatment to recover gold, palladium and platinum from the walls of the sample bottles, followed by high-resolution (HR)–ICP–MS analysis. Rocks will undergo a multi-acid total digestion followed by ICP–MS–OES for over 50 elements. FA–ICP–MS will be utilized for gold and PGEs analyses and selected rock samples will undergo whole rock analysis.

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Metric Conversion Table

Conversion from SI to Imperial			Conversion from Imperial to SI		
SI Unit	*Multiplied by*	*Gives*	*Imperial Unit*	*Multiplied by*	*Gives*
			LENGTH		
1 mm	0.039 37	inches	1 inch	**25.4**	mm
1 cm	0.393 70	inches	1 inch	**2.54**	cm
1 m	3.280 84	feet	1 foot	**0.304 8**	m
1 m	0.049 709	chains	1 chain	20.116 8	m
1 km	0.621 371	miles (statute)	1 mile (statute)	**1.609 344**	km
			AREA		
1 cm^2	0.155 0	square inches	1 square inch	**6.451 6**	cm^2
1 m^2	10.763 9	square feet	1 square foot	**0.092 903 04**	m^2
1 km^2	0.386 10	square miles	1 square mile	2.589 988	km^2
1 ha	2.471 054	acres	1 acre	0.404 685 6	ha
			VOLUME		
1 cm^3	0.061 023	cubic inches	1 cubic inch	**16.387 064**	cm^3
1 m^3	35.314 7	cubic feet	1 cubic foot	0.028 316 85	m^3
1 m^3	1.307 951	cubic yards	1 cubic yard	0.764 554 86	m^3
			CAPACITY		
1 L	1.759 755	pints	1 pint	0.568 261	L
1 L	0.879 877	quarts	1 quart	1.136 522	L
1 L	0.219 969	gallons	1 gallon	**4.546 090**	L
			MASS		
1 g	0.035 273 962	ounces (avdp)	1 ounce (avdp)	28.349 523	g
1 g	0.032 150 747	ounces (troy)	1 ounce (troy)	**31.103 476 8**	g
1 kg	2.204 622 6	pounds (avdp)	1 pound (avdp)	**0.453 592 37**	kg
1 kg	0.001 102 3	tons (short)	1 ton (short)	**907.184 74**	kg
1 t	1.102 311 3	tons (short)	1 ton (short)	**0.907 184 74**	t
1 kg	0.000 984 21	tons (long)	1 ton (long)	**1016.046 908 8**	kg
1 t	0.984 206 5	tons (long)	1 ton (long)	**1.016 046 90**	t
			CONCENTRATION		
1 g/t	0.029 166 6	ounce (troy)/ ton (short)	1 ounce (troy)/ ton (short)	34.285 714 2	g/t
1 g/t	0.583 333 33	pennyweights/ ton (short)	1 pennyweight/ ton (short)	1.714 285 7	g/t

OTHER USEFUL CONVERSION FACTORS

	Multiplied by	
1 ounce (troy) per ton (short)	31.103 477	grams per ton (short)
1 gram per ton (short)	0.032 151	ounces (troy) per ton (short)
1 ounce (troy) per ton (short)	20.0	pennyweights per ton (short)
1 pennyweight per ton (short)	0.05	ounces (troy) per ton (short)

Note: Conversion factors which are in bold type are exact. The conversion factors have been taken from or have been derived from factors given in the Metric Practice Guide for the Canadian Mining and Metallurgical Industries, published by the Mining Association of Canada in co-operation with the Coal Association of Canada.

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